Volume 13 APRIL 1929 Number 4

BULLETIN

of the

American Association *of* Petroleum Geologists

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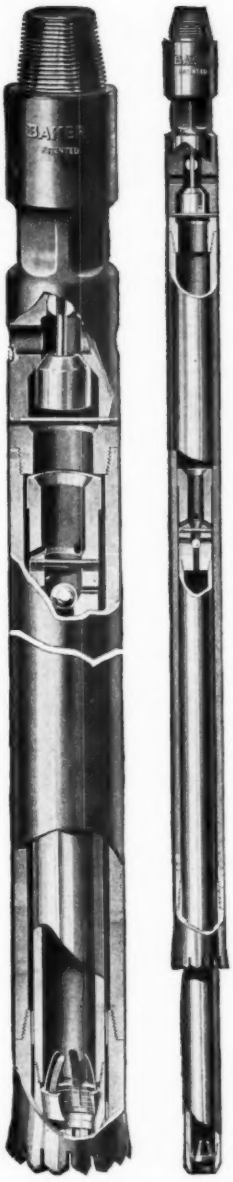

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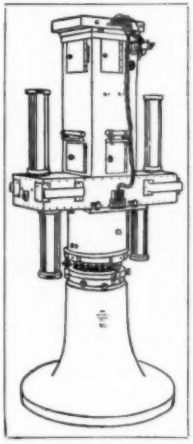

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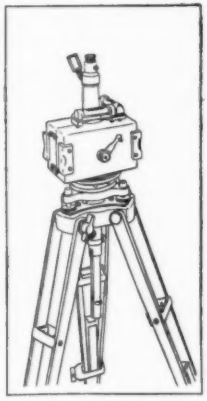

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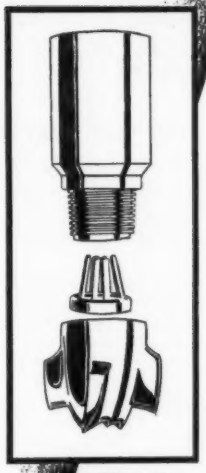

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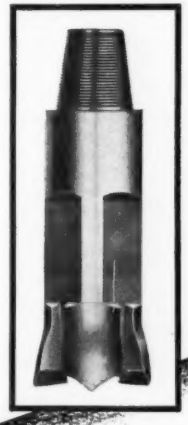

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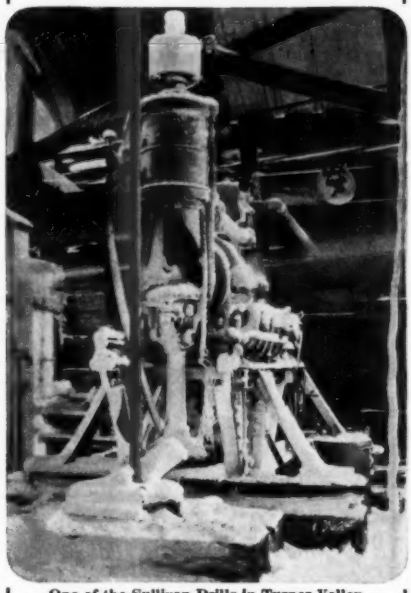

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The Bulletin of the American Association of Petroleum Geologists is published by the Association on or about the 15th of each month. Editorial and publication office, 504 Tulsa Building, Tulsa, Oklahoma, Post Office Box 1852.

The subscription price to non-members of the Association is $15.00 per year (separate numbers $1.50) prepaid to addresses in the United States, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Dominican Republic, Canary Islands, El Salvador, Argentina, Bolivia, Brazil, Colombia, Chile, Costa Rica, Ecuador, Guatemala, Honduras, Nicaragua, Peru, Hayti, Uruguay, Paraguay, Hawaiian Islands, Philippine Islands, Guam, Samoan Islands, Balearic Islands, and Spain.

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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
BOX 1852
TULSA, OKLAHOMA

Entered as second-class matter at the Post Office at Tulsa, Okla., under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

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Volume 13 Number 4

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APRIL 1929

GENERATION OF OIL IN ROCKS BY SHEARING PRESSURES[1]

J. E. HAWLEY[2]
Madison, Wisconsin

I. THE PROBLEMS—METHODS OF DETERMINING THE SOLUBLE ORGANIC CONTENT OF OIL SHALES

ABSTRACT

A series of papers of which this is the first presents the results and some conclusions regarding the generation of oil in rocks by shearing pressures. In this first paper attention is confined to the method of determining the soluble organic content of oil shales. Many problems were encountered in this phase of the work, both in the preparation of shales for extraction, actual extraction, and drying the extracts to eliminate the solvents, and in determining the effects of catalysts on extraction. Interesting discoveries include the fact that oxidation renders some of the insoluble organic matter soluble, and that shales which have been subjected to high shearing pressures give an extract with more volatile hydrocarbons than shales not sheared. A few conclusions are drawn regarding the origin of oil shales and the nature of their organic matter. These are opposed to the theory that oil shales are shales containing inspissated petroleum.

INTRODUCTION

Research on Project No. 1, "The Generation of Oil in Rocks by Shearing Pressures," has been carried on since September, 1926, first

[1]Manuscript received by the editor December 29, 1928. This series of papers contains results obtained in an investigation on "The Generation of Oil in Rocks by Shearing Pressures" listed as Project No. 1 of American Petroleum Institute Research. Financial assistance in the work has been received from a research fund of the American Petroleum Institute donated by the Universal Oil Products Company. This fund is being administered by the Institute with the coöperation of the Central Petroleum Committee of the National Research Council. W. J. Mead is director of the project.

[2]American Petroleum Institute research fellow, University of Wisconsin. Introduced by W. H. Twenhofel.

at the University of California and later at the University of Wisconsin. The work has been under the direction of Warren J. Mead. Sufficient data have now been secured to warrant publication of the results and the conclusions which may so far be reached. This project was originally undertaken at the suggestion of David White, who saw the fundamental importance of the problem in its relation to the origin of petroleum.

The investigation has, in general, followed the plan outlined in the *Bulletin* of the American Petroleum Institute, Vol. VII, No. 20 (March 31, 1927).

This plan was based on the assumption that oil is generated from commonly-supposed "mother rocks," typical oil shales or marine bituminous shales, under loading of superposed strata, by pressures[1] (mainly intermittent horizontal thrusts) operating through long periods of time with heat of depth of burial, heat of friction and heat of chemical change, and with added pressures of the resulting gases and oils.

The variable factors considered to have a possible effect in the conversion of the organic matter of oil shales to oil thus are at least seven in number. Heat, already known to be sufficient in itself to cause a conversion of the organic material to oil, may be of three origins, and of variable intensity. Pressures may be due to mechanical shearing stresses, or to generated gases. Solutions or solids may have some catalytic effect, and time, combined with any of the other factors, may give pronounced effects.

To perform experiments in the laboratory duplicating natural conditions as nearly as possible would mean combining all or nearly all the possible factors. Geologic time can not be duplicated and great difficulties are presented in working with high pressures and temperatures. Regarding the quantitative effect of any of the variables combined with time, we have exceedingly few data, the only contribution being that of Maier and Zimmerley[1] on the effect of temperature and time on the conversion of organic matter in oil shales to "bitumen." Accordingly, in attempting the solution of the problem, it has first been the purpose of the investigators to evaluate and determine the separate effect of two of the variables at a time. Those factors which have received some attention to date are variable shearing pressures and time; heat of friction and shearing; heat, gas pressures and time; catalysts; and catalysts and

[1]Pressures are considered as being sufficient in amount to produce deformation by fracture or by flow. High shearing stresses on rocks made so rigid by containing pressures that no deformation could occur, might also be considered.

[1]C. G. Maier and S. R. Zimmerley, *Univ. Utah Bull. 14* (1924), pp. 62-71.

shearing pressures. Experiments combining mechanical pressures and temperature are being carried on at present.

Throughout, typical oil shales from various localities have been used in the investigation.

While it was not anticipated that shearing pressures alone with time, but without heat, would produce any marked effect on the organic matter of oil shales, it was considered necessary to investigate their effect, since it is probable many oil-bearing strata have never been deeply buried; therefore, never subjected to very high temperatures in that way. Furthermore, the question as to whether some of the complex long-chain hydrocarbon molecules considered present in oil shales could be sheared into lighter, more soluble molecules required an answer. And, since earlier investigators reported the supposed formation of oil in oil shale by shearing pressures without heat, considerable attention has been given to this phase of the work.

To measure the influence of any of the factors on the oil shale treated, the amount of organic matter which is soluble in organic solvents has been determined for the treated and untreated shale. In the early part of the work, it was found that the extraction procedures in use needed considerable refinement before any minute difference caused by shearing pressures could be detected. The determination of an accurate procedure uncovered many related problems, some of which are given in the first paper of this series. Following this, the results of many shearing-pressure tests on oil shales and conclusions derived therefrom will be presented in the second paper.

Related to the main problem of the effect of shearing pressures on typical oil shales is another series of experiments which have been made. These deal with the effect of shearing pressures on shales containing infiltrated oil and on artificial mixtures of kaolin with oil or with "bitumens" derived from oil shale by extraction. The purpose has been to determine whether shearing pressures will cause the expulsion of oil or "bitumens" from shales, and if so, in what proportion. This problem follows naturally from the first, since if shearing pressures (and other factors) cause the generation of oil in shales, the question arises, will these same pressures force the oil from the shales into near-by sands, or will the oil remain in the shale unless moved by forces other than pressure? The results of this work are to be discussed after the pressure tests on oil shales.

Results of the experiments dealing with the effect of heat and gas pressures on oil shale will be considered in a third report, and this will

be followed by a later one covering the effect of combined heat and pressure.

PREVIOUS WORK

That shearing pressure is one of the most important causes of chemical and physical change in an organic deposit such as coal, particularly when of one origin and one age, has been set forth by David White in several papers.[1] The thrust or shearing pressure, originating in earth movements, "is essentially horizontal in direction, acting on and transmitted with diminishing (progressively compensated) force through the buried and loaded coal-bearing strata." The changes brought about in coals are marked by progressive devolatilization, deoxygenation, and increase in fixed carbons. In general the degree of carbonization of a coal bed varies directly with the intensity of thrust compression and progresses toward the source of the thrust, supposedly the area of greatest thrust intensity, depending, of course, on the duration and intensity of the stress exerted on any given beds. Such pressure metamorphism

> has converted lignite (brown coal) successively into sub-bituminous coal, bituminous, semi-bituminous, semi-anthracite, anthracite, and even graphitic coal . . . The physical evidences of thrust pressure, such as jointing, folding, faulting, schistosity, crushing, etc., become in general more highly developed and conspicuous not only in the coal, but in the environing strata also, as the alteration of the coal proceeds; so that the regions of greater change in coal show the physical effects of greater pressure.

Seeming anomalies are the "abnormally high percentages of volatile matter sometimes found in coals lying in folds (or folded fault blocks) and generally to be observed near thrust faults in coal fields" and "the greater reduction of volatile matter in many of the areas of little or no folding," even though these are more remote from the source of the thrust stress. In the anomalous areas of intense folding, crumpling, and faulting, it is held that the coals have ordinarily been able, by virtue of their folded and faulted position, "to escape the full intensity or renewal of the thrust," and even though they show the greatest deformation, they may not have been subjected to as great or as prolonged stresses as more competent, perhaps more heavily-loaded, adjoining beds which did not fold or fault, but transmitted the stresses to blocks beyond, and deformed, if at all, essentially by cubic compression. In the latter regions, "in which the beds are not folded, progressive devolatilization of

[1] David White, *Econ. Geol.*, Vol. 3 (1908), p. 311; Vol. 4 (1909), p. 280; *U. S. Bur. Mines Bull. 29* and *Bull. 38;* "The Origin of Coal" (with R. Thiessen), *Jour. Wash. Acad. Sciences*, Vol. 5 (1915), pp. 189-212; *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 71 (1925), pp. 253-81.

the coal is accompanied by mechanical changes (such as those previously listed) which in a lesser degree are shared by the enclosing rocks." Furthermore, increase in volatile matter in coals in highly-folded or faulted regions has been shown to progress as the folding becomes closer or the faulting more intense. The interpretation of such an occurrence is that the greater the deformation, the greater the relief gained by the beds from further stress, and even though these deformed strata did suffer greater or as great intensity of stress as more remote beds, the duration of the stress was less in these areas where relief was gained than in areas where no buckling or breaking occurred. Hence, the regions where relief from stress was gained early may show less devolatilization of the coal than "more distant horizontal series beyond it and farther from the source of pressure."

The same author regards the "pressure metamorphism" of coals as having occurred at relatively low temperatures. The temperatures are "the results of heat of depth of burial, heat of chemical reaction, and, what is far more important, heat of friction under the compressing stresses."[1] "Time and temperature may, within certain limits, be substituted one for the other, and pressure is partly interchangeable with both." However, the pressure metamorphism seems to be the controlling factor in the alteration of coals, even in regions which have suffered igneous intrusion and the resulting additional heat, as well as shearing or thrust stresses.

The importance of White's conclusions is obvious in their relation to the effect of shearing pressures on organic deposits such as oil shale. Oil shales have been shown as different from some coals (the humic) in the type of the organic content, but they are similar on the whole, and are classed with coals of the bog-head or algal class, which is represented chiefly by cannel coals. Both contain spore and pollen exines, seed envelopes, and certain cuticles "with resinous, waxy or oily protective substances," but the oil shales contain also a greater amount of "other fat, oil, and albuminoid-producing animal and plant ingredients." Both cannel coals and oil shales are characterized by a high hydrogen and low oxygen content. Though the exact chemical compounds present in both the coal and shale are not known, it seems highly probable that shearing pressures would have approximately the same influence on both in effecting chemical changes.

[1]David White, *Amer. Inst. Min. Met. Eng.*, Vol. 71 (1925), p. 271.

Experimental work on the shearing of oil shale has already been carried on by others.[1] McCoy and Trager[2] reported that shearing pressures produced globules of oil from oil shale. The pressure apparatus used by these investigators consisted of a steel spool with pistons, similar to those used by Adams and Bancroft,[3] but built to withstand much lower pressures. Pressures ranging from 5,000 to 6,000 pounds caused the deformation of shale cores encased in steel jackets. The cores failed, seemingly, by fracture. Qualitative tests on the shale before and after deformation gave a positive indication of oil, compared with a negative test before. No appreciable heat was developed during the shearing of the shale. Trager suggests that the organic matter in the shales was distilled by the frictional heat of molecular displacement, yielding hydrocarbons.

Van Tuyl and Blackburn[4] used a pressure apparatus similar to that of McCoy and Trager. Shale cylinders made from oil shale from Elko, Nevada, and Grand Valley, Colorado, were subjected to pressures ranging from 7,653 to 43,367 pounds per square inch. The shale cylinders are reported to have yielded to deformation by flowage. After deformation, the shales were ground to pass an 80-mesh screen and were then extracted with chloroform, as were comparable samples of the original shale. No essential difference in the amount of soluble organic matter in the shales before and after deformation was found and no oil was produced. Flowage experiments were also conducted on shale at temperatures ranging from 100° to 220° C. The differences between the amounts of soluble matter obtained by extraction from the original and from flowed shale were again inappreciable. Continuous extraction of the flowed shale and original shale samples, through long periods of time, however, showed the amount of soluble bitumen in the flowed shale to be consistently less. From this, and from the extraction results of flowed and unflowed shales which were subjected to a later heat treatment, the writers concluded that pressures tended to render the "kerogen" less soluble. Their final conclusion was to the effect that oil shales subjected to flowage pressures at ordinary temperatures and at high temperatures equivalent to those which would exist normally at a depth

[1]A. W. McCoy, *Jour. Geol.*, Vol. 27 (1919), pp. 252-62; Vol. 28 (1920), pp. 366-71.

[2]E. A. Trager, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), p. 301.

[3]F. D. Adams and J. A. Bancroft, *Jour. Geol.*, Vol. 25 (1917), pp. 597-637.

[4]F. M. Van Tuyl and C. O. Blackburn, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 1 (Jan., 1925), pp. 158-64; No. 8 (Aug., 1925), pp. 1127-42.

of more than 8,000 feet in the earth's crust would not yield oil in important amounts; therefore, that oil shales are not genetically related to important petroleum deposits.

It is clear that the authors here did not take into consideration the geologic time factor, which becomes of great significance in view of the work of C. G. Maier and S. R. Zimmerley.[1]

The chemical dynamics of the transformation of the organic matter of oil shales to "bitumen" was investigated by Maier and Zimmerley.[1] Previous work of a similar kind had been done by McKee and Lyder,[2] who concluded that the "pyro bitumens" (of shales) do not decompose to form petroleum oils as a primary product of decomposition, but that the first substance obtained is a heavy solid or semi-solid "bitumen," and "that bitumen is formed at quite a definite temperature, 400°-410°C. . . . the petroleum oils formed being the results of the decomposition or cracking of the heavy bitumen."

Maier and Zimmerley used Tertiary oil shale from Soldier Summit, Utah, yielding 40 gallons of oil per ton on destructive distillation. The rate of formation of "bitumen" was studied in both open and closed tubes at temperatures varying from 275° to 365° C. Some oil was formed at the higher temperatures. The open-tube method was found unsatisfactory, but the closed-tube method showed that the formation of bitumen is a function of both the time and the temperature, that the transformation does not begin at any one temperature, and that the amount of bitumen formed is independent of the temperature provided the time of heating is long enough. From the data gathered it was calculated that a 1 per cent conversion of organic matter to bitumen at a temperature of 100° C. would require 8.4×10^5 years. Heat treatment of other shales from Colorado, Nevada, Australia, Scotland, and Kentucky yielded products similar physically to "bitumen" of the Utah shale. However, the rate of formation of bitumen in these other shales differed, and no data are yet available regarding them, though this problem is being further investigated by A. J. Carlson, of the University of California.

ACKNOWLEDGMENTS

The investigators are greatly indebted to F. H. Probert, L. C. Uren, and A. J. Carlson, of the University of California, for the use of a laboratory and equipment in the Department of Petroleum Technology.

[1]C. G. Maier and S. R. Zimmerley, *op. cit.*, p. 62.

[2]R. H. McKee and E. E. Lyder, "Thermal Decomposition of Shales," *Jour. Ind. and Eng. Chem.* (July, 1921).

To C. G. Maier, of the Bureau of Mines Experimental Station, Berkeley, California, thanks are due for his most valuable suggestions, especially with regard to the chemical aspect of the investigation. To Professor Davis, of the Civil Engineering Department, thanks are also due for the facilities afforded in the Testing Laboratories of the University of California. The writer is also indebted to C. W. Muehlberger, of the University of Wisconsin, for help in investigating organic solvents and suitable methods of eliminating these from extracts. To the director of this project, W. J. Mead, acknowledgment is gratefully made for suggestions and constructive criticism throughout.

Acknowledgment has already been made of the fact that this project was suggested by David White. Dr. White has contributed greatly in suggesting various experiments and in offering helpful and constructive criticisms from time to time.

Determination of Soluble Organic Content of Oil Shales

Since it has been shown by others[1] that the transformation of organic matter of oil shales to oil on heating takes place by at least two reactions in which a soluble "bitumen" is first formed and then oil, the determination of the effect produced by high shearing pressures and other factors on oil shale has been made by ascertaining the amount of organic matter in the shales which is soluble in organic solvents before and after treatment. In the early part of the investigation it was found that the originally soluble organic matter obtained by extraction could be varied considerably by the treatment given the shale in preparing it for extraction. Accordingly it was necessary to determine the influence of all possible factors in this process. This included the influence of grinding and heat of friction developed in grinding, drying and oxidation of the shale, a study of suitable organic solvents, time of extraction and rate of solution of the organic matter, methods of drying the extracts, and the effect of possible catalysts on the amount of extract obtainable. A factor directly related to the main problem of the effect of shearing pressures on oil shales is the heat of friction developed in the grinding itself, during which great shearing pressures are generated locally on small particles of shale.

Thoughout this part of the investigation Colorado oil shale from DeBeque has been used.

[1] C. G. Maier and S. R. Zimmerley, *op. cit.*
M. J. Gavin, "Oil Shale," *U. S. Bur. Mines Bull. 21D* (1924), p. 27.

PREPARATION OF SHALES FOR EXTRACTION

GRINDING OIL SHALE

1. Shale ground to a size which will pass an 80-mesh standard Tyler screen (.175-mm. openings) yields essentially the same amount of soluble organic matter on extraction for a period of 12 hours as shale ground to pass a 100-, 150-, or 200-mesh screen. Shales ground to much finer sizes after great shearing pressures have been applied yield similar results. This is in accord with the results of Van Tuyl and Blackburn.[1] The rate of solution is admittedly a function of the amount of surface available on which the solvent may act. Difference in rate of solution of extract from shales of various sizes can be detected when measured at frequent intervals during the first few hours of extraction. For a 12-hour period of extraction, however, the total amounts of extract obtained from a shale of less than 80-mesh and from one of less than 200-mesh, are not sufficiently different to justify fine grinding.

TABLE I

EXTRACTION RESULTS ON COLORADO (DEBEQUE) OIL SHALE WITH CHLOROFORM 12-HOUR PERIOD

	Mesh	*Per Cent Extract*
1.	> 80 < 14	1.93
2.	< 80	2.14
3.	< 100	2.08
4.	< 150	2.18
5.	< 200	2.12

2. Grinding oil shale at room temperature, by hand, in either an iron or a porcelain mortar, does not produce sufficient heat of friction to cause any measurable change in the soluble organic content of the shale. This was demonstrated by grinding shale frozen by means of liquid air. Results of extraction of this shale and of shale ground at room temperatures checked exactly (Table II).

TABLE II

EFFECT OF TEMPERATURE AND ATMOSPHERE IN GRINDING OIL SHALE

How Ground	*Per Cent Extract (With Carbon Tetrachloride)*
Frozen with liquid air < 70-mesh	1.287
In air at room temperature < 70-mesh	1.289
In nitrogen at room temperature < 70-mesh	1.32

3. Oxidation of the organic matter in the shales during grinding in air is insufficient in amount to cause any appreciable difference in yield

[1] F. M. Van Tuyl and C. O. Blackburn, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), No. 1, p. 158.

of extract. To determine this, shales were ground in atmospheres of air and nitrogen. The difference in extracts obtained is within the limits of experimental error.

DRYING OIL SHALES. DETERMINATION OF MOISTURE CONTENT

Drying oil shales prior to extraction in order to free them of their natural moisture content, at a temperature of 105° C., has been found to decrease the soluble organic content as much as 10 or 20 per cent, depending on the length of the drying period. The decrease seems to be due to the volatilization of organic material rather than to any effect the absence of moisture might have. That the higher yield from the undried shale is not altogether due to moisture dissolved by the solvent, is shown by drying the extract at 105° C., at which temperature not only water, but also some of the volatile constituents of the extract would be eliminated. In spite of such drying of the extracts, a higher yield is still obtained from undried shales. Whether the shale is dried in air, in vacuum, or in an atmosphere of nitrogen, the extract is less than when the shale is not dried.

To avoid this loss of extract, shales are extracted without drying, a moisture determination being made on separate samples, and the percentage extract from dry shale is calculated.

TABLE III

EFFECT OF DRYING OIL SHALE PRIOR TO EXTRACTION

Run Numbers	*How Dried*	*Hours Dried*	*Per Cent Loss H_2O+Vol.*	*H_2O or O_2 Regained*	*Per Cent Extract*	
					Dried Shale	*Undried Shale*
12*-14	Vacuum	14	.29	Nil	1.14	1.29
22 -21	Vacuum	8.5	.29	Nil	1.14	1.29
20 -23	Vacuum	7	.27	Nil	1.04	1.29
4 -14	Air	50	Dried and oxidized	.0527 grams	1.00	1.29
7 -14	Air	20	Gain in weight	O_2	1.15	1.29
7C-11C	Nitrogen	2 (80°C.) 8 (105°C.) 3 (80°C.)	.49	.26H_2O	2.04	2.17
8C-15C	Nitrogen	14.5 (105° C.)	.49	Nil	1.905	2.18

*First number, test dried; second number, test not dried.

OXIDATION OF ORGANIC MATTER IN OIL SHALES

While drying oil shales in air in a regulated electric oven to free them of moisture, it was found impossible to bring them to a constant weight. At 105° C. an early loss in moisture (and probably hydrocarbons) was followed by persistent gains in weight, until a weight greater than the original moist weight of the shale was obtained. That this gain in weight of the shale was due to oxidation was readily shown.

In drying the shale at 105° C. in vacuum or in nitrogen, thus eliminating oxygen, a constant weight could be obtained after 5 or 6 hours. A. J. Carlson,[1] in drying samples of organic matter of different concentrations obtained from oil shales, found the percentage gain in weight (by oxidation) varied almost directly with the concentration of organic matter in the samples. W. L. Finley and A. D. Bauer,[2] in a recent paper, have also noted the fact that oil shale oxidizes at temperatures of 116°-186° C.

Although the gain in weight of the shales due to oxidation was not sufficient to alter greatly the calculation of the amount of extract obtained, it did interfere with the accurate determination of loss in weight of the shale after extraction. Furthermore, the actual chemical changes involved, and their effect on the amount and nature of the extract obtained, opened an interesting field for investigation, and, in addition, required the determination of the effect of oxidation of the shale during grinding and shearing.

The effect of drying and oxidizing shales at 105° C. prior to extraction is to give an initially lower percentage of extract. This is shown by drying shale in air, in vacuum, and in nitrogen, and by extracting the shale without drying. The drying itself, as already noted, has this same effect, but the decrease in extract is somewhat greater in the shale dried and oxidized (Test 11) than in the shale dried in vacuum or in nitrogen (Tests 9 and 10, Table IV). This, however, may be due to the fact that the oxidized shale had a much longer drying time at 105° C. than the others; if this is true, the decrease in extract is largely due to the loss of volatile constituents from the originally soluble matter of the shale. Finley and Bauer[3] noted a decrease in extract obtained from shales oxidized at 135° C., and account for this either by volatilization of extract-

[1] Personal communication.

[2] W. L. Finley and A. D. Bauer, *U. S. Bur. Mines Tech. Paper 398* (1926).

[3] *Op. cit.*, p. 10.

able matter or by oxidation, making the extractable matter insoluble in the solvent (carbon tetrachloride). They favor the oxidation theory as the shale increased in weight over the original weight of moist shale. Better evidence that the soluble matter will form an insoluble compound after long exposure to air is found in the formation of a fine brown precipitate in a solution of carbon tetrachloride and extractable matter, but the rate of this reaction and its quantitative importance is not known, and the exact effect of oxidation if it causes a decrease in extractable matter is still uncertain.

In marked contrast to this phenomenon is the effect produced by oxidation of the organic matter after the shale has been extracted and the originally soluble material has been removed. Re-extraction of the shale shows that some new soluble material has been formed and that the total amount of extract may be increased in this way much above what is obtained by continuous extraction, in spite of any initial loss caused by drying. That there is no doubt of this effect of oxidation is shown by Table IV, a summary of five experiments in which samples of Colorado oil shale were subjected to different drying conditions both before extraction and between periods of extraction.

From Table IV, the rather marked increase in extract obtained after drying and oxidizing oil shales is apparent. Even after a shale has been extracted for a period of 219 hours, the percentage extract is increased considerably by oxidation, as is illustrated in Test 12.

The only suitable explanation of the increased solubility of the organic matter by oxidation so far found was suggested by C. G. Maier.[1] It is that oxygen might easily enter any unsaturated compounds, which are known to be plentiful in oil shales, at the position of a double bond, possibly weakening the long-chain hydrocarbon and allowing a splitting at this point. It is highly improbable that this reaction would involve the insertion of atomic oxygen, but rather it is to be expected that the introduction of two atoms of oxygen would take place with the formation, ultimately, of a carboxyl group and a soluble fatty acid.

Discussing the nature of the double bond, A. F. Hellman[2] points out that the first step is the formation of an addition product by the taking up of two hydroxyl groups, and that "when a substance containing a double bond is oxidized, the chain is always severed at the double bond." Water is required as a catalytic agent, and is regenerated by continued

[1] Personal communication.

[2] *Text Book of Organic Chemistry*, J. Wiley & Sons (New York, 1912), pp. 153-70.

oxidation. An example of such a reaction, which fits the condition very well, is that of oleic acid, $C_{18}H_{34}O_2$. Thus:

$$CH_3 \cdot (CH_2)_7 \cdot CH \cdot (CH_2)_7\, COOH + 2O_2 = CH_3\,(CH_2)_7\, C(=O)-OH$$

(Oleic acid → Pelargenic acid

$$+ OH-C(=O) \cdot (CH_2)_7\, COOH$$

+ Azelaic acid)

Furthermore, Burks and Smith[1] have recently found that of the extracted material of oil shale, 60-70 per cent consists of complex fatty acids. The origin of these in part may be related to past oxidation, such as could occur before and during deposition of the organic matter contained in the shales.

In order to determine the effect of oxidation on the saturation of the extracted "bitumens" obtained from shales, iodine numbers were run on several samples. These are as follows:

	Iodine Number
1. Composite sample of "bitumen" obtained from vacuum-dried Colorado shale	53.8
2. "Bitumen" from shale which was not dried or oxidized	41.7
3. Composite sample of "bitumen" from air-dried and oxidized Colorado shale	18.2

The results indicate that the "bitumen" obtained from air-dried and oxidized shales is approximately two or three times as saturated as that from unoxidized shales, or, in other words, the "bitumen" from the unoxidized shales has two or three times the number of double bonds existing in the oxidized samples. This of course does not account for the increase in soluble extract obtained by oxidation, and to explain that it is necessary to follow Hellman, as before, in supposing oxidation attacks the insoluble hydrocarbons, which also may be in part unsaturated, and causes the splitting off of lighter and more soluble fatty acids. This is supported by the results obtained in extract Test 12, Table IV, on Colorado shale. The marked increase in yield, here, after almost all the originally soluble organic matter had been removed, shows that oxidation must have changed some of the insoluble organic matter to a soluble form.

Should the oxidation theory mentioned as a possibility in explaining the original decrease in extract from oxidized and dried shales (page 313)

[1]Dana Burks, Jr., and J. P. Smith, Chemistry Department, Stanford University. Personal conversation with Mr. Burks.

TABLE IV

EFFECT OF OXIDATION ON COLORADO OIL SHALE

Test Number	*Number of Extraction*	*Drying Conditions*	*Hours*	*Hours of Extraction*	*Per Cent Extract*	*Total Per Cent Extract*
9	First	Vacuum	13	12	1.05	1.05
	Second	Vacuum	9	12	0.10	1.15
	Third	Air—O_2 gain 0.74 per cent	55	12	0.216	1.373
				36 total		
10	First	Nitrogen	10	12.5	1.06	1.06
	Second	Vacuum	10	12	0.127	1.187
	Third	Vacuum Air—O_2 gain 0.83 per cent	12	12	0.061	1.248
				48.5 total		
11	First	Air—O_2 gain 0.62 per cent	85	16	0.92	0.92
	Second	Air—O_2 gain 0.46 per cent	68	13	0.194	1.114
	Third	Air—O_2 gain 0.76 per cent	42	12	0.094	1.208
				41 total		
				Hours Total		
12	First	Vacuum	14	2	1.009	1.009
	Second	Nil		2– 4	.062	1.071
	Third	Nil		18– 22	.066	1.137
	Fourth	Nil		24– 46	.039	1.176
	Fifth	Nil		24– 70	.025	1.201
	Sixth	Nil		72–142	.054	1.255
	Seventh	Nil		32–170	.017	1.272
	Eighth	Nil		49–219	.020	1.292
	Ninth	Air—O_2 gain .22 per cent		12–231	.21	1.502
14	First	Nil		1– 2	1.14	1.14
	Second	Nil		2– 4	.049	1.189
	Third	Nil		18–22	.103	1.293
	Fourth	Nil		24–46	.066	1.359
	Fifth	Nil		24–70	.064	1.423
	Sixth	Nil		28–98	.048	1.471

be true, why does not oxygen attack and render insoluble the newly-made extractable matter? A difference in chemical composition between the original and the "manufactured" extractable matter may account for this, or a difference in the speed of the oxidation reactions. One difference in the composition of the extracts from oxidized and from unoxidized shale has already been determined, the former being more saturated

than the latter, or containing fewer double bonds. The presence of fewer double bonds in the "manufactured" soluble hydrocarbons may therefore account for the difference in behavior of these and original soluble hydrocarbons under oxidizing conditions. If both original and prepared hydrocarbons may be oxidized to insoluble compounds, the rate of the reactions is clearly different, that of the original "bitumen" being the faster.

An increase of extractable matter was obtained by McKee[1] by chlorinating shales instead of oxidizing them. It seems probable that the explanation of the production of more soluble "bitumen" or extract by this method is the same as that given for oxidation.

EXTRACTION OF OIL SHALES

ORGANIC SOLVENTS

The soluble organic matter of oil shales has been extracted in Soxhlet extractors with different solvents and for different periods of time. All solvents used have been carefully purified by fractional distillation, and later dried over anhydrous sodium sulphate of calcium chloride.

The essential requisites of a suitable solvent have been found to include (1) chemical stability, (2) relatively high vapor pressure, so that the solvent may be evaporated from the extract without undue loss of the extract, (3) average solvent power, and (4) non-inflammability.

In the early part of the work carbon tetrachloride was used as a solvent extensively, chiefly on account of its chemical stability. It was later found, however, that this solvent could not readily be evaporated from the extract without losing a considerable part of the extract.

Other solvents used include those listed in Table V with the per cent extract and remarks as to their character. A method[2] was devised to determine, for the halogen solvents, the shortest possible drying time and lowest drying temperature at which the solvent could be completely evaporated with little loss of extract. The extract is heated on a water bath till the "bitumen" is soft, and moist air is drawn over it. This air is then sucked through platinumized asbestos at a low red heat, and finally through a silver nitrate solution. Any halogen solvent vapor liberated from the extract will be decomposed in passing over the red-hot platinum in the presence of water, and the halogen will be precipitated

[1] R. H. McKee, *Oil Shale* (New York, 1925).

[2] The writer is indebted to C. W. Muehlberger for this method.

by the silver nitrate solution. Chloroform was found to extract suitable amounts of organic material and to be evaporated completely from the extract at 50° C. in a current of nitrogen after two hours. It is also suitable because of economy and non-inflammability.

Table V gives the extraction results on Colorado shale ground to less than 80-mesh and extracted for a period of 24 hours.

TABLE V

EXTRACTION RESULTS ON COLORADO SHALE

	Solvent	*Per Cent Extract*	*Remarks*
1.	Carbon tetrachloride	1.92	Long drying at 105° C. does not remove all CCl_4 and large losses of extract take place
	B. P. 76° C.	1.898	
2.	Ethyl bromide	1.930	Satisfactory but expensive; easily evaporated at low temperatures
	B. P. 36° C.	1.955	
3.	Petroleum ether	1.359	*Low yield*, very inflammable; easily evaporated
	B. P. < 50° C.		
4.	Ethylene chloride	3.698	Yield varies—difficult to eliminate solvent
	B. P. 82-83, 5° C.	2.297	
5.	Chloroform	2.173	Satisfactory — solvent eliminated from extract by drying 2 hours at 50° C. in N_2 current
	B. P. 69-61° C.	2.183	
		2.152	
6.	Acetone	1.738	(12 hours of extraction) cf. 1.84 per cent with CCl_4, low yield; part of dissolved material precipitates before extraction completed
	B. P. 56° C.		
7.	Methyl potash	1.00	Low yield in cold

Other solvents such as ether and carbon disulphide were not seriously considered on account of their highly inflammable nature. These could be satisfactorily removed from the extract by evaporation at low temperatures.

TIME OF EXTRACTION

A standard time for extraction was adopted when it was found that with carbon tetrachloride and chloroform, after a period of 24 hours, the yield of extract was very low and regular, the production curves flattening to low-angle straight lines. These are illustrated in Figure 1.

A long-time extraction test, No. 12, was made on Colorado shale with carbon tetrachloride after drying to a constant weight in vacuum.

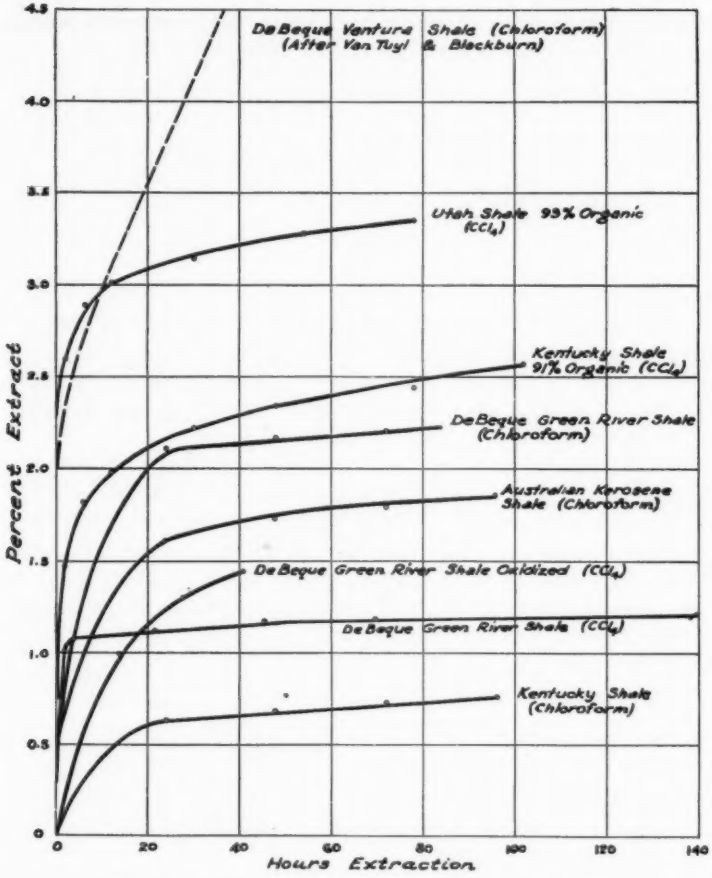

FIG. 1.—Extraction curves for shales with different solvents.

The shale was extracted for a period of 219 hours. Extraction was continuous except for short intervals when the stills were replaced with fresh solvent. Prior to extraction and after each addition of fresh solvent, nitrogen was blown through the extraction apparatus, to the top of which a U-tube with a mercury seal was attached. In this way oxygen was eliminated from the system, and the possibility of oxidation of the organic matter of the shale during extraction was thus avoided. Consider-

ing the total bitumen obtained in 219 hours as 100 per cent, the following figures show the percentage extraction at different time intervals:

Hours of Extraction	*Per Cent Extraction*
2	77.9
4	82.8
22	87.8
24	89.0
46	90.8
70	92.9
142	97.0
170	98.4
219	100

Contrary to some of the findings of Van Tuyl and Blackburn,[1] chloroform extraction gave results similar to those with carbon tetrachloride, showing that approximately 2-3 per cent of the Colorado shales are readily soluble in this solvent within 24 hours, and that thereafter only a very small steady yield is obtained.

The character of the curves obtained for percentage yield of extract through varying and long periods of time, suggest that, after a period of approximately 24 hours, the limit of solubility has been reached, or that a reaction occurs (at a very slow rate) by which fresh but very small amounts of soluble organic matter are formed. A relatively low percentage of the organic matter in the shales is soluble in the average solvents, and more can not be extracted unless some reaction such as oxidation occurs.

DRYING OF EXTRACTS AND EVAPORATION OF SOLVENTS

In the investigation of suitable drying temperatures and periods[2] to eliminate the solvents used from the extracts obtained, it was found that considerable losses of volatile extract occurred at temperatures even below 100° C. This was determined by drying past the point where all the solvent had been removed.

Drying extracts at much lower temperatures, 35°-40° C. under reduced pressure, also caused a loss of extract. By many trials with chloroform it was found that for the average amount of extract obtained from a 10-gram sample of shale, drying in a current of nitrogen for 2 hours at 50° C. would remove all but a trace of chloroform without much loss of

[1] F. M. Van Tuyl and C. O. Blackburn, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), No. 8, pp. 1138-39.

[2] The extract is concentrated in a weighing bottle to a semi-solid condition by drying at room temperature. Further drying is needed to eliminate traces of the solvent.

extract. The time and temperature, of course, vary for the different solvents.

VARIATIONS IN AMOUNT OF VOLATILE CONSTITUENTS IN EXTRACTS FROM SHALES SUBJECTED TO HIGH PRESSURES

In drying the extracts from shales sheared by high pressures, to remove the solvent and obtain a constant weight, it was discovered that these extracts at 105° C. lost considerably more than extracts from unsheared shale. The results are as follows:

Run	*Total Load in Pounds*	*Moisture Volatile Loss on Drying Shale*	*Extract Hours Dried 105° C.*	*Per Cent* Extract*	*Per Cent Net Loss Drying Extract*
**[16	200,000	0.67	24-189	1.449-1.281	11.6
**[38	Nil	0.52	24-182	1.554-1.409	9.3
[42	200,000	0.38	2- 34	1.820-1.621	10.9
[43	Nil	0.32	2- 34	1.634-1.580	3.3

*Weight of extract after drying for time given at 105° C.
**Brackets indicate shale from same diamond-drill cores.

In the preceding table it should be noticed that the net losses of extract include some remnant of the solvent. The losses are figured on the weight of extract after drying 24 hours, and are greater for runs 16 and 42 than for runs 38 and 43, even though the former show a higher loss of moisture plus volatiles in the drying of the shale before extraction, and despite the fact that in the former the sheared shale yields less, and in the latter, more extract than the unsheared specimens.

An explanation of the greater volatile content of sheared shale extract over that of unsheared shales includes two possibilities. One is that the shearing actually splits up hydrocarbon molecules to form lighter and more volatile compounds, the total amount of soluble matter remaining approximately the same. No proof of this has yet been found. The other possibility is one indirectly related to the shearing, and touches on the uncertain behavior of oxidation of the organic compounds present in shales. In so far as it has been shown that oxidation of the insoluble organic matter of Colorado shale produces soluble compounds, we are on safe ground. These new compounds are of lighter molecular weights and some of them may be sufficiently light to be volatile at 105° C. depending on the position of the double bonds in the original long-chain insoluble compounds. The following table, furthermore, shows that

highly sheared shales will oxidize more rapidly than unsheared shales, though the total amount of oxygen gained is almost constant.

	Weight Dry Shale	*Hours Dried*	*Oxidized Shale*	*Net Per Cent Gain in Weight*
Shale not sheared	6.8793	18	6.9285	.716
		+21	6.9800	1.461
Shale sheared	6.9469	18	7.0449	1.41
		+21	7.0492	1.475

Hence it is possible that the increase in volatile matter in sheared shales is here not so much due to the shearing as to oxidation of the shale during shearing, with the formation of lighter organic molecules from the heavier insoluble, long-chain compounds. That this reaction would not be common in the natural deformation of oil shales at depth should be noticed, inasmuch as reducing conditions should predominate on account of the plentiful organic matter present in the shales. For this reason the change in volatile content of the shales by shearing is not regarded as an effect to be considered in natural occurrences.

EFFECT OF CATALYSTS ON EXTRACTABLE PORTION OF OIL SHALES

Colorado oil shale has been treated with different reagents to determine their effect on the amount of extractable material. Two methods have been used.

1. Shales have been treated with the reagents for a given time, the reagent has then been removed, the shale dried and then extracted.

2. The reagent has been added directly to the shale or solvent during extraction and has later been removed from the extract where possible.

1 (*a*). Shales have been treated with dilute solutions of hydrochloric acid ($1/10N$), of sodium hydroxide ($1/10N$), and of sodium chloride (5 per cent) for one week at room temperature. The residues of the shale were then washed thoroughly and dried to a constant weight in vacuum and extracted with carbon tetrachloride.

The extracts obtained are all slightly less in amount than those obtained from the same shale which was not treated with a reagent. The lower yields are probably due to prolonged drying of the treated shales.

1 (*b*). Colorado shale ground to less than 80-mesh was treated with a 2 per cent solution of sulphuric acid for 24 hours. The acid was then

Test Number	Reagent	Extract Per Cent of Original Weight of Shale
31	*HCl*	1.165–1.29
32	*NaOH*	1.149
33	*NaCl*	1.258
34	Nil	1.362

washed out completely and the sample dried at 55° C. until its previous weight was obtained. The extract obtained in 24 hours with chloroform was 2.18 per cent as compared with 2.06 per cent for the untreated shale. The increase is too slight to be of importance.

2 (*a*). Glacial acetic acid was added to chloroform and the shale in the extraction apparatus. In the first 24 hours 10 cc. were added—2 cc. at a time. The effect of the acid could not be noticed until the extraction was nearly completed. Then, adding fresh acid, additional organic material went into solution, giving the previously colorless solvent a distinct brown tinge. The extract after 24 hours was 2.57 per cent compared with 2.06 per cent extract without acid. This increase, however, may be due simply to the solvent effect of the acid not neutralized by the carbonates of the shale.

It has been suggested that the increase in extract in this case is due to glacial acetic acid hydrolyzing insoluble calcium or magnesium fatty acids, thereby rendering them soluble. It is known that glacial acetic acid is capable of causing such a reaction. Kunkler and Schwedhelm[1] found that calcium salts of fatty acids, when heated to 270°-320° C., give hydrocarbons like those found in lubricating oils; such salts have been suggested as intermediate products in the formation of petroleum.

2 (*b*). A 10 per cent mixture of anhydrous aluminum chloride and Colorado shale ground to less than 80-mesh was extracted with chloroform for 24 hours. The extract obtained was more than 150 per cent greater than that obtained from shale extracted only with chloroform. The extraction results are:

10 per cent $AlCl_3$ and shale — 5.7 per cent of shale

Shale alone — 2.1 per cent

The product obtained by extracting the chloride shale mixture hardens on cooling after elimination of the chloroform, and breaks up

[1]David Holde and Edward Mueller, *Chemistry in Oils*, J. Wiley & Sons (1915), p. 7.

into fine angular fragments resembling in physical properties a pitch or a hydrocarbon such as gilsonite, rather than the ordinary semi-liquid obtained.

The exact manner in which the chloride causes an increase in the soluble extract is not yet known. More experiments with the reagent are planned.

2 (*c*). Colorado shale was extracted with a solution of methyl potash, (40 grams *KOH* per liter of methyl alcohol). The extraction was done while the solution was cold, fresh solvent being added and allowed to stand on the shale every 24 hours for 7 days. A good coloration was obtained at first, and a small coloration even on the last day—indicating that the extraction was not altogether complete. The solution was then neutralized with hydrochloric acid, the salt filtered off, and washed free of extract with alcohol. The alcohol was then distilled off, and the extract filtered, dried, and taken up with chloroform, which was later evaporated. The percentage extract obtained was approximately 1 per cent of the shale. The product obtained was a brown semi-liquid much like that obtained by ordinary extraction methods.

2 (*d*). Colorado oil shale was mixed with approximately 26 per cent Lloyd's reagent, a highly adsorptive fuller's earth. This shale alone yields, on extraction with chloroform, 2.13 per cent soluble extract, whereas the mixture yields only 1.65-1.73 per cent calculated on the basis of percentage of oil shale present.

A composite sample of extracts from Colorado oil shales was added directly to Lloyd's reagent and was mixed thoroughly with the earth by diluting the extract with chloroform, and by stirring until the solvent had been evaporated. The amount of extract added was approximately 12.48 per cent of the mixture. On extraction of the same mixture with chloroform for a period of 24 hours only 11.3 per cent extract was recovered. A total or almost total recovery might of course be obtained by extracting for a very long time.

The results of these experiments indicate at least that adsorbents like kaolin or similar hydrous aluminum silicates occurring in shales cause a decrease in the solubility or rate of solution of some of the organic matter in oil shales. It is not to be concluded, however, that the low solubility of the organic matter as a whole is due to this fact only.

SUMMARY

In the procedure for the determination of the soluble organic content of oil shales the possible factors which might cause a change in the nature of the organic matter have been studied.

The size of grain to which the shale should be ground, less than 80-mesh, has been determined and agrees with the results of Van Tuyl. Grinding at room temperatures has been found to produce no effect on the shale as compared with grinding at low temperatures. Any heat of friction developed is insufficient to render soluble a measurable amount of the insoluble organic matter.

Drying oil shale to free it from its natural moisture content, whether in vacuum, in nitrogen, or in air, causes a loss of soluble organic matter. Drying of the oil shale in air at 105° C. causes first a loss of soluble extract, by volatilization probably of the originally soluble matter, but later oxidation causes the formation of freshly soluble compounds. It is suggested that these are due to the breaking down, by oxidation, of unsaturated long-chain hydrocarbon molecules at the position of the double bonds, with the formation of lighter and more soluble fatty acids.

Of many solvents used, chloroform has been the most satisfactory, especially as it may be volatilized from the extracts without undue loss of the extract.

Extraction curves of several oil shales show rather definitely the insoluble nature of most of the organic matter in the common organic solvents. This insoluble material can not, then, be a form of petroleum. The straight-line nature of the extraction curves after a period of 24-48 hours shows that the limit of solubility of the organic matter has been almost reached, or that some reaction occurs during extraction at a very slow and regular rate. Exactly what such a reaction could be is not known and the former possibility is favored. Of the soluble matter derived from oil shales by extraction, Burks and Smith, as noted on page 315, have found that 60-70 per cent consists of complex fatty acids.

In the drying of extracts to free them of the solvent used, it is almost impossible to prevent some loss of extract by volatilization. Drying at 35° - 45° C. under reduced pressure also causes a loss, and a standard procedure has to be adopted. With chloroform solvent, only a low loss of extract results from drying at 50° C. in a current of nitrogen. After a period of two hours all of the chloroform will have been evaporated.

Drying of extracts from sheared shales has shown a higher content of volatiles than occurs in extracts of unsheared shales. The explanation favored is that intense shearing with the development of greater surfaces promotes oxidation under experimental conditions. Oxidation is known to proceed faster on sheared than on unsheared shales, and, further, it has been shown to produce lighter, more soluble, and probably more volatile compounds from the insoluble organic matter of shales. Hence,

oxidation is likely to be the cause producing more volatiles than the shearing itself. Since oxidizing conditions would not be expected in the shearing of oil shales at any depth in nature, its effect is not considered of importance in the present problem.

Oil shale from Colorado, when treated with reagents such as sulphuric acid, hydrochloric acid, sodium hydroxide, and salt (*NaCl*) solutions, yields essentially the same amount of soluble extract as before treatment. Acetic acid causes a slight increase, and anhydrous aluminum chloride, a considerable increase in the solubility of the organic matter, but none has sufficient effect ever to be important from an economic standpoint.

Adsorbents like fuller's earth mixed with oil shale, or "bitumen" derived from oil shale by extraction, have been found to decrease the solubility of the extractable matter.

EXTRACTION PROCEDURE FOR OIL SHALES

The following extraction procedure has been developed after careful study of all the factors so far known to influence the percentage of extract obtainable from oil shales.

Preparation of shale.—The shale is ground in air in a porcelain or steel mortar, fine enough to pass an 80-mesh standard Tyler screen. A quarter of the sample is then weighed in a glass weighing bottle and dried in a nitrogen atmosphere in an electrically regulated oven at 105° C. A 5-6 hour drying period is sufficient to eliminate the moisture without an undue loss of volatile hydrocarbons. After cooling in a nitrogen atmosphere the sample is weighed and the moisture content determined.

Extraction of shale.—The remainder of the sample, which is not dried, is extracted with chloroform for a period of 24 hours, in a Soxhlet extraction apparatus, using fat-free paper thimbles and electric hot plates, at a low heat. The solution of chloroform and organic matter is then distilled down, the chloroform recovered, and the concentrated organic matter transferred to a weighing bottle. The remainder of the solvent is then evaporated slowly at 35° C. (in 24 hours or more), and finally the sample is dried in a current of nitrogen for 2 hours at 50° C. This eliminates the last traces of chloroform.

CONCLUSIONS REGARDING THE ORIGIN OF OIL SHALES AND THE NATURE OF THEIR ORGANIC MATTER

In connection with the investigation of a suitable extraction procedure for oil shales, it is worth while here to point out some conclusions which may be reached or at least suggested by the experimental data secured. These deal mainly with the origin of the oil shales and throw a very little light on the chemical behavior of the organic matter.

The theory of E. H. Cunningham-Craig that oil shale is "the colloidal combination of the fine adsorbent matter of the shale with an inspissated petroleum which may have migrated for a great distance before reaching its present stratigraphic position"[1] seems to have been satisfactorily refuted by Van Tuyl and Blackburn[2] on the basis of lack of stratigraphic evidence and volume changes. That some of the otherwise soluble organic matter of the shales, however, is adsorbed by the colloidal mineral matter of the shales, is supported by some of the experiments described, in which the solubility of the extracts of Colorado shale was decreased after mixing with fuller's earth or Lloyd's reagent.

The fact that oxidation of the insoluble organic matter of Colorado oil shale causes the formation of new soluble matter probably by the splitting of long-chain unsaturated hydrocarbons is evidence in itself that the organic matter is not all simply adsorbed by the mineral matter, but is of so large molecular constitution that its solubility as a whole is negligible. Were the organic matter all simply adsorbed, neutralization of the charges on the adsorbed matter should liberate them and increase their solubility, but the failure of either acids or bases (see p. 323) to render soluble all the organic matter present is somewhat unfavorable to this theory.

The formation of soluble fatty acids by oxidation of the insoluble organic compounds in oil shales, together with the presence of soluble fatty acids in the shales as they occur to-day, suggests that oxidation is a factor to be considered in the formation of oil shales, and that the already soluble compounds originated in part at least by past oxidation of more complex molecules, perhaps preceding and during the deposition of the organic débris. David White[3] has noted the plentiful evidence of shallow-water origin of many oil shales which in places have features indicating temporary exposure to the air.

Regarding the solubility of the organic matter ("kerogen") of oil shales, Gavin[4] states:

> The amount soluble, based on the weight of the shale, is small in all cases, but it is to be noted that a considerable percentage of the organic matter is soluble in most of the solvents used. A solubility of 2 per cent means an extraction of 40 pounds, or, roughly, 5 gallons to the ton.

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), p. 180.

[2] *Ibid.*, p. 1129.

[3] W. H. Twenhofel *et al.*, *Treatise on Sedimentation* (1926), p. 302.

[4] M. J. Gavin, "Oil Shale," *U. S. Bur. Mines Bull. 210* (1924), p. 27.

Van Tuyl and Blackburn,[1] on the other hand, state that "kerogen" of several oil shales is slowly soluble in chloroform and that the amount of extract varies directly with the time of treatment. Extraction of De Beque, Colorado, oil shale for 309 hours yielded nearly one-half of the total organic matter.

The present investigators have found, however, after extracting many oil shales with carbon tetrachloride and chloroform, that the organic matter has a limited solubility (of the order of 2 per cent for Colorado shale) as indicated by the nature of the extraction curves, and that for an appreciable extraction beyond this point some reaction is required. The nature of such reactions which might occur during extraction of oil shale is questionable. Oxidation, dehydration, or even hydrolysis of the solvent may be factors, but further data are required on this point.

In summary, therefore, oil shale such as that from DeBeque, Colorado, contains organic matter of at least two kinds. One part is small in amount and readily soluble in common organic solvents. This contains more than 50 per cent complex fatty acids, some of which are unsaturated. Some of the soluble portion is volatile at temperatures of 105° C., or even lower. Some may be adsorbed by colloidal matter sufficiently to retard the rate of solution, and some of the constituents may be oxidized to form insoluble compounds.

The larger amount of the organic matter is insoluble in organic solvents. A part of this consists of unsaturated long-chain hydrocarbons which may be oxidized and broken up into lighter, soluble fatty acids. Some may be present as calcium or magnesium salts of fatty acids which are rendered soluble by the action of glacial acetic acid. A large part is not rendered soluble by oxidation or acetic acid, and is not simply adsorbed by colloidal mineral matter. These properties serve to emphasize the fact that the organic compounds in oil shale are not forms of inspissated petroleum.

[1] *Op. cit.*, p. 1128.

GENERATION OF OIL IN ROCKS BY SHEARING PRESSURES[1]

J. E. HAWLEY[2]
Madison, Wisconsin

II. EFFECT OF SHEARING PRESSURES ON OIL SHALES AND OIL-BEARING ROCKS

ABSTRACT

This paper, the second of a series on the generation of oil in rocks by shearing pressures, gives details regarding experiments performed with oil shales from Colorado, Australia, Kentucky, and Cleveland, Ohio. The shales were subjected to high shearing pressures of varying intensity and under different conditions, so that they yielded by either fracture or flow. Nearly all the tests were conducted at room temperature. In no case was any oil generated, and the shearing appears to have had little effect on the solubility of the organic matter. One effect noticed is the occurrence of more volatile matter in extracts from sheared shales than in extracts from shales not sheared. This, however, is explained by oxidation and is not applied to natural occurrences.

Other experiments include the shearing of Colorado oil shale with various catalysts present and of a California shale containing oil. By the latter it is demonstrated that high shearing pressures will squeeze out practically no oil from a highly saturated shale.

A general conclusion, based on the experiments, is that high shearing pressures on oil shales at low temperatures and throughout relatively short periods of time are quantitatively not important in the generation of oil from such rocks. It is also pointed out that where the deformation of oil shales occurs even partly by fracture and under considerable containing pressures, an increase in volume is brought about which will cause a reduction of fluid pressures. Should pressure be proved to influence the change of organic matter in oil shales towards oil, this reduction of fluid pressures may be important in explaining any actual changes brought about in nature.

Shearing-Pressure Tests on Oil Shales

TYPES OF PRESSURE EXPERIMENTS

Pressure tests of three kinds have been made with oil shales to determine the effect of shearing on the organic material at room temperatures. These include shearing (1) solid shale cores encased in long

[1]Manuscript received by the editor, December 29, 1928. This paper contains results obtained in an investigation on the Generation of Oil in Rocks by Shearing Pressures, listed as Project No. 1 of the American Petroleum Institute Research. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by the Universal Oil Products Company. This fund is being administered by the Institute with the coöperation of the Central Petroleum Committee of the National Research Council. W. J. Mead is director of the project.

[2]American Institute research fellow, University of Wisconsin. Introduced by W. H. Twenhofel.

copper or steel tubes, (2) ground-up shale in short copper and steel cylinders, and (3) solid shale cores in a steel apparatus of spool type. In the first two methods, deformation is accomplished largely by fracture, and in the third by flowage.

LONG COPPER AND STEEL TUBES

Metal tubes of either annealed copper tubing or semi-annealed Shelby steel tubing, with a 1-inch diameter and ⅛-inch thickness, are cut in 7-inch lengths. The ends are threaded and fitted with heavy brass caps and lead washers (Fig. 1).

FIG. 1.—Copper tubes with shale core before and after deformation. Deformed tube has been subjected to a total load of 205,000 pounds, or 35,150 pounds per square inch, Test 5. Increments of load used were 5,000 pounds. Time, 1 hour and 40 minutes.

Diamond-drill cores of shale, 1 inch in diameter and 3 inches in length, cut parallel with the bedding of the shale, are placed in the center of the tubes and sealed there by forcing them down in molten Woods metal (M. P. 73° C.), and chilling the tube quickly. In this way, a perfect fit is insured for the shale core. The remaining space in each of the metal tubes is then filled with pure quartz sand of 35-40 mesh, which is tightly packed by tamping. The sand forms a highly incompressible packing at the ends of the shale, and is held in place by the brass caps.

The tubes are then placed horizontally between cast iron or steel blocks, 2½ inches square and 1 inch thick, with slightly bevelled edges, the shale core lying directly between the blocks. Pressures are applied at right angles to the long dimension of the tube and shale core. In this way the circular section of the shale is deformed to a somewhat flattened ellipse or a lemniscate, and by this deformation a maximum amount of shearing is obtained.

Still other experiments are under way in which steel tubes with walls greater than ⅛ inch in thickness are used. With these the rigidity of the shale is increased greatly, and greater pressures are required to deform the shale by shear.

In some experiments, where diamond-drill cores of shale could not be obtained, powdered shale was closely packed in the center of the metal tubes for a length of 3 inches. This procedure was also used where it was desired to introduce different solutions or solvents with the shale under pressure.

SHORT COPPER OR STEEL CYLINDERS

Powdered shale ranging in size from less than 14-mesh to less than 80-mesh was placed in 1½-inch lengths of either copper or steel pipe, made from the same tubing as that used in the first method. Copper plates, 1/16 inch in thickness, were placed at the ends, and pressures were exerted parallel with the length of the cylinders. This method avoids entirely any differences which might arise in grinding unsheared oil shale used as a check and in grinding the sheared shale after deformation. It also permits the exertion of much greater pressures than are possible in the first method.

The short cylinders filled with shale deform rapidly under load at first and bulge at the center. The ends of the cylinders cut into the copper plates and remain fairly rigid and fixed. As the load is increased, bulging continues until the porosity of the powder or broken shale has been reduced to a minimum, and at this point the specimen becomes much more rigid, further load causing a slow bulging, until at the end a

disc of hardened and compacted shale is obtained. The product, however, is intensely fractured, as is evidenced by the ease with which it may be later broken (Fig. 2).

FLOWAGE TESTS

Shearing-pressure tests in which shale cores are deformed by flowage rather than by fracture have been made. For these, hollow steel cylin-

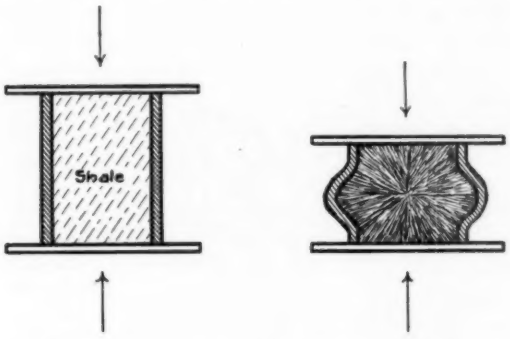

FIG. 2.—Diagram of copper cylinder used for shearing oil shales.

ders of a spool shape and fitted with pistons are used. In design and dimensions, these are a duplicate of those used by Adams and Bancroft[1] (Fig. 3). Two sets of spool cylinders were made, one of the chrom-vanadium, and the other of nickel steel. The pistons are of polished drill-rod carbon steel, ¾ inch in diameter. The thickness of the wall in the narrow part of the spool is .28 cm. and .30 cm., respectively. Shale cores cut normal to the bedding were turned down in a lathe to fit exactly the hollow steel spools. The cores used are 1½ inches long and ¾ inch in diameter. The apparatus permits a maximum pressure of 100,000 pounds per square inch to be brought on the shale cores, and approximately 35,000 pounds per square inch before deformation begins.

This spool type of apparatus has also been used under conditions in which the time variable was lengthened to months, and in which it was desired also to introduce a temperature factor. For maintaining high pressures through long periods of time two presses were constructed.

[1]F. D. Adams and J. A. Bancroft, *Jour. Geol.*, Vol. 25 (1917), pp. 597-637.

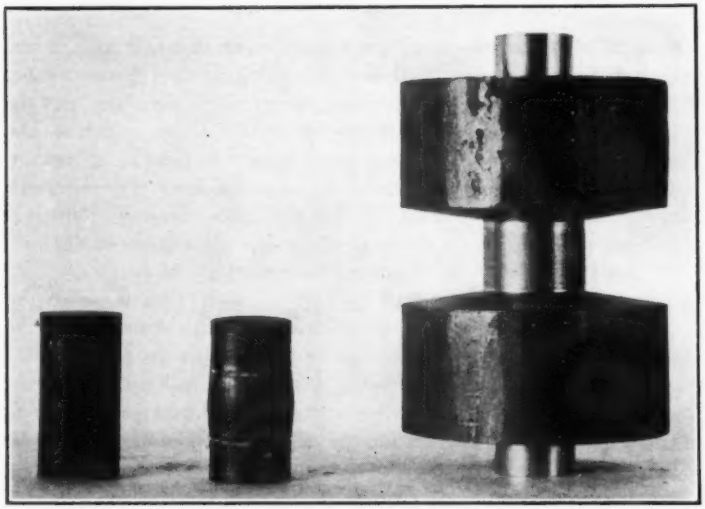

FIG. 3.—Spool apparatus used in flowage experiments, showing the shale core before and after deformation. Deformed core suffered a load of 104,000 pounds per square inch.

They are made with three movable plates of 1½-inch hot rolled steel, which slide on three 1-inch steel rods. Between the two lower plates are three standard double-coil freight-car springs, each with a capacity load of 18,000 pounds, and between the middle and upper plates is placed the steel cylinder enclosing a shale core. One of the pistons of the spool is set on a small ball plate to insure even loading. Nuts at the ends of the three rods permit the presses to be closed at any load desired. A total load of more than 50,000 pounds may be placed on the apparatus, pressures which are more than sufficient to deform the pistons and steel cylinders used.

Where it was desired to raise the temperature of the shale while under load, a small electric furnace was constructed which would fit around the steel cylinders, the ends of which were then packed with magnesite. Thermocouples were used to measure the temperature, and a rheostat for control. In order to retain any gases volatilized during such heat treatment and the pressure generated by these gases, the steel pistons were hollow ground, giving a fine feather edge which, with pressure, would expand and effectively seal the specimen.

ENERGY EXPENDED ON SHALE BY SHEARING PRESSURE

In order to determine the energy expended on the shale cores, it was necessary to ascertain the work done in deforming the steel or copper tubes or cylinders. For this, cores of tallow (stearic acid) were used and the deformation noted for each increment of load. Tallow, as Adams and Bancroft[1] state, moves under load, with the development of an amount of internal friction which is so small as to be negligible. The difference between the energy required to deform the tubes encasing tallow and that required to deform the shale-filled tubes gives a measure of the work done on the shale cores as illustrated in Figures 4 and 5.

In the tests with copper or steel tallow-filled tubes, it was found impossible to apply loads as great as those used with shale cores, or to accomplish as much deformation on the tubes, since the tallow would flow away from the area of pressure, bulging and finally rupturing the free ends. Accordingly, in shale tests where the deformation (flattening of tube) exceeded that produced in the tallow-filled tube, no data can be secured beyond a certain point, as shown in Figure 6.

Deformation curves, constructed by plotting the horizontal dimension of the tubes or cylinders against the total load applied, were obtained in all experiments except where the load was applied very rapidly. Against these curves have been plotted the curve for a tallow-filled tube, and a true curve obtained by difference. The relative amount of work done on the shale in each experiment, therefore, is represented by the area below the true curves.[2] The final load, in pounds per square inch, has been calculated for each test by dividing the total load by the area of the flattened tube.

MECHANICAL EFFECTS OF SHEARING SHALE

In the experiments with copper and steel tubes, it was found that the copper and steel would flow considerably and if the pressures were applied rapidly the tubes would rupture by shear. From these ruptures, the shale would flow out only when the pressure was relieved. When the pressures were applied more slowly, however, no ruptures occurred.

As the pressure is applied, the ends of the shale cores are pinched by the pressure blocks. The ends of the shale cylinders bulge outward into the sand packing, and vertical-tension fractures develop. The effects produced in the central part of the shale cores are shown in the accom-

[1] *Op. cit.*, p. 609.

[2] *Ibid.*, p. 607.

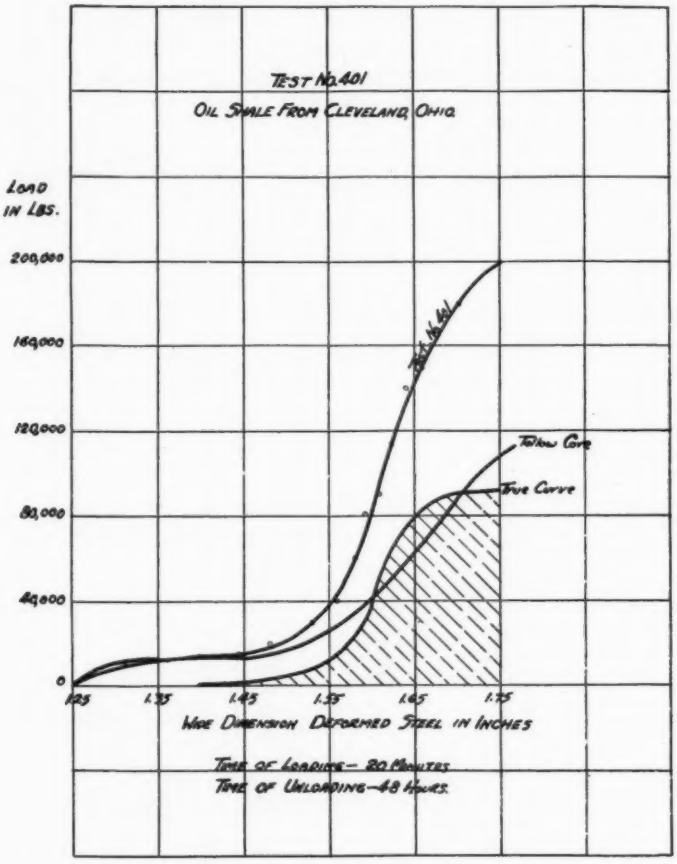

FIG. 4.—Deformation curve of Test No. 401 on Cleveland, Ohio, oil shale encased in steel tube.

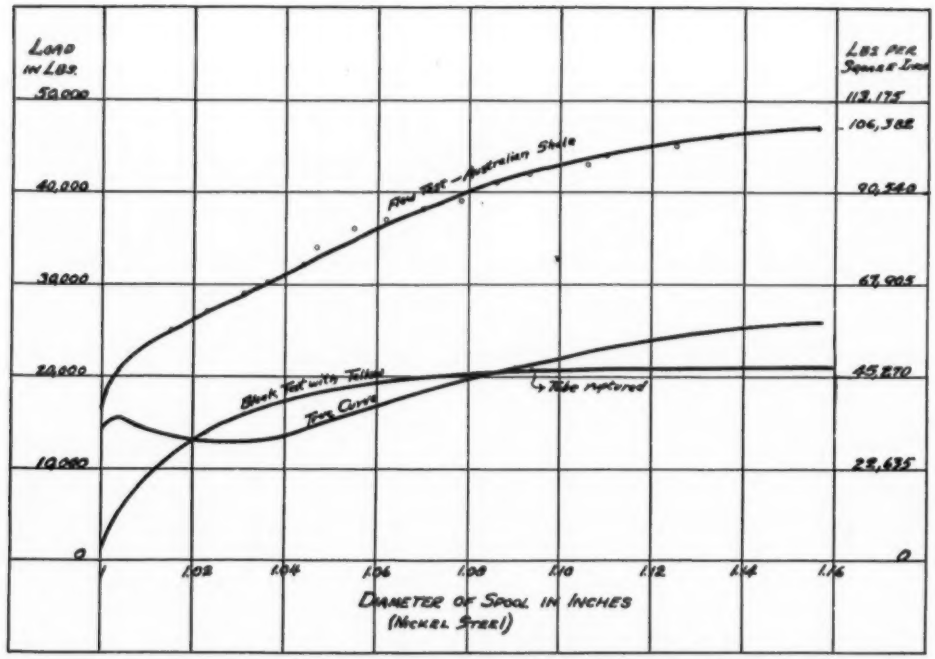

FIG. 5.—Deformation curve of test on Australian oil shale in which shale yielded by flowage.

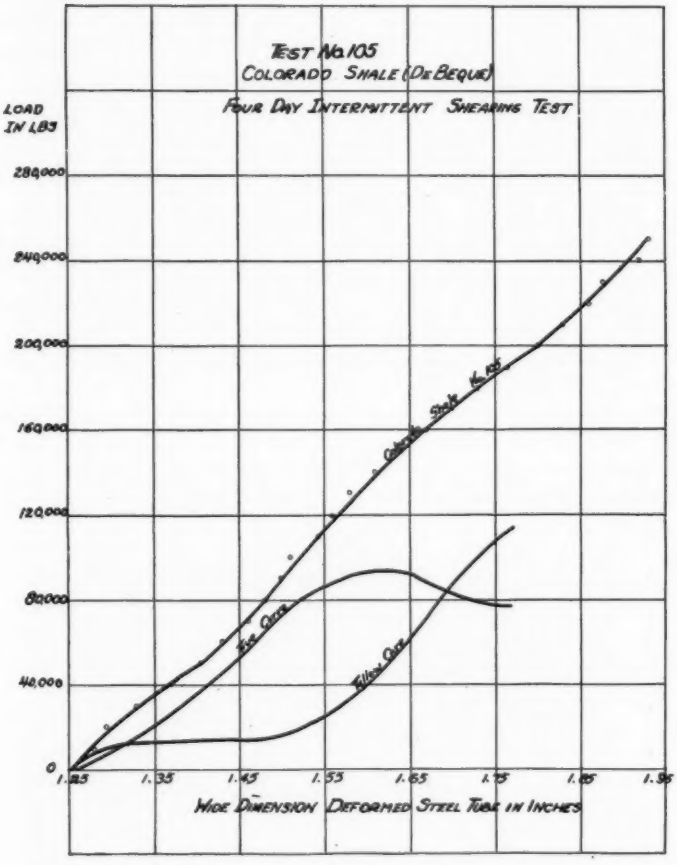

FIG. 6.—Deformation curve on Colorado oil shale encased in steel tube.

panying photographs (Figs. 7 and 8). In all experiments, slightly open or tight fractures develop throughout, making an angle with the vertical direction of compression of slightly less than 45° and corresponding with the direction of the planes of maximum shear. The relative amount of shearing produced in this manner is obviously much greater than that in the cores encased in steel spools. In the latter, deformation by shearing (when the shale yields by fracture) is confined to a smaller area in the shape of a cone, as has been demonstrated by Adams and Bancroft.[1] It is also evident that the larger amount of intensely sheared shale obtained by the tube method renders more reliable the results of subsequent extraction with organic solvents.

In the experiments with short copper and steel pistons, the broken and powdered shale, under pressure, as already noted, is first compacted, with a reduction of porosity to a minimum. Thereafter the shale yields by intense shearing, though here, too, the maximum shearing occurs in two cones as illustrated in Figure 2.

Where the shale was encased in the steel spools, deformation was accompanied by flowage without the development of visible shear fractures. That some shearing of the shale did occur, however, is probable,

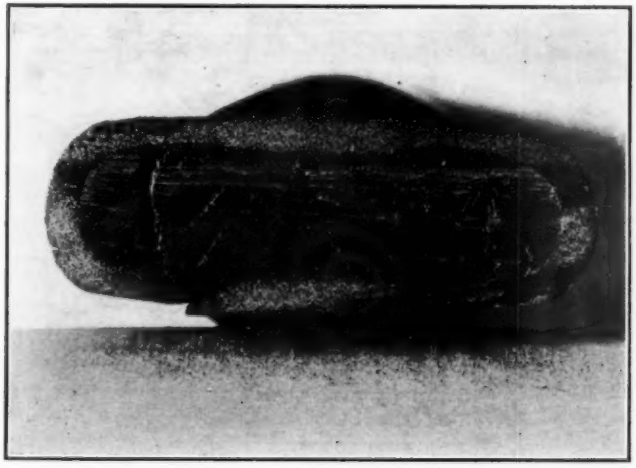

FIG. 7.—Cross section of shale core deformed in copper tube, Test 1. Load of 200,000 pounds was applied rapidly.

[1] *Op. cit.*, p. 625.

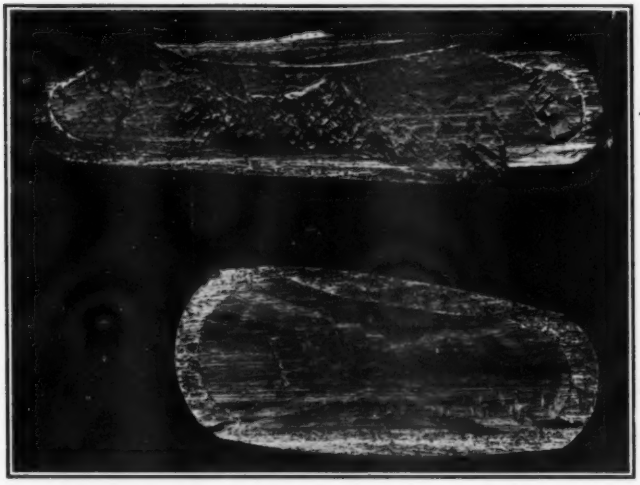

FIG. 8.—*A*. Cross section of shale core deformed in copper tube, Test 2(*b*). Total load 200,000 pounds; increment of load, 2,000 pounds; time, 5 hours. Final load 38,095 pounds per square inch on area of 5.25 square inches.

B. Cross section of shale core deformed in steel tube, Test 6. Total load 205,000 pounds. Area of flattened surface, 3.525 square inches. Final load, 58,155 pounds per square inch. Time, ½ hour.

since a relatively small amount of local movement in and between the grains of the rock would be sufficient to account for the deformation made. In the long-time flowage experiments, very nearly all of the deformation occurred in the shale during loading, and not during the long subsequent interval in which the shale was under load. It was thought possible, however, that under a long-continued strain any changes in the organic matter liable to be caused by load would take place in sufficient amount to be measured.

TIME VARIABLE IN SHEARING SHALES — SHEARS OF INTERMITTENT NATURE

The time intervals during which shales were subjected to shearing pressures were varied greatly. The fastest deformation was the continuous application of 300,000 pounds load in 5 minutes; the slowest, of 250,000 pounds in 4 days. In the former, pressures were applied continuously; in the other tests, the increment of load ranged from 2,000 pounds to 10,000 pounds. In these the deformation produced was measured before an additional load was applied. From the moment flattening

of the tube begins, the shale core yields by shearing. Yielding means a loss of part of the load, but an increase in pressure over that previously applied is required to further deform the cylinder. This condition is maintained until the metal container ruptures. Thereafter the load falls off and can not be brought up again. At the point of rupture of the metal tubes the shearing was discontinued. Thus, it should be noticed, the deformation was of the nature of intermittent shears—since deformation was accomplished almost instantaneously with, or within a few seconds after, the application of each increment of load. As Adams and Bancroft have pointed out, under load and with strong containing pressures, relatively weak rocks such as shale acquire a great rigidity, and the stress difference necessary to overcome this rigidity increases greatly with an increase in the containing pressures.

MEASUREMENT OF HEAT DEVELOPED BY FRICTION DURING PRESSURE TESTS

In previous tests made by other investigators, it has been observed that no appreciable heat of friction was developed in the shale by the shearing pressures, as evidenced by the fact that paraffin placed on the apparatus did not melt or soften.

Attempts were made to detect any rise in temperature in the copper tubes encasing shale during deformation by means of an electric thermocouple and a potentiometer. The thermocouple was soldered to a free edge of a copper tube so as to escape deformation. The tube with its shale core was then placed between asbestos sheets and subjected to a load increasing steadily to a maximum of 300,000 pounds in 5 minutes. No rise in temperature was detected, though the part of the copper tube lying between the pressure blocks was slightly warmer to the touch than the undeformed ends.

No satisfactory method has been found for obtaining anything approximating accuracy in the measurement of the heat of friction developed, because of the large surfaces exposed and the rapid conduction of heat away from the pressure blocks. Nor do further experiments in the measurement of friction seem justified. As already noted, Maier and Zimmerley have shown that the rate of formation of "bitumen" or soluble organic matter from Utah shale at 100° C. is only 1 per cent in 8.4×10^5 years. Whether the heat is from an external source, or due to the friction developed internally by deformation from the shearing of particles or even of molecules,[1] as has been suggested, the effect should be the

[1] E. A. Trager, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), p. 301.

same. Accordingly, there is little need of measuring the amount of this heat of friction, which at best is not capable of raising the temperature of the shale more than a few degrees when the deformation is very rapid, and probably less when the deformation is slow, inasmuch as the effect on the organic matter could never be detected through such a minute length of time. Cognizance is taken of the fact that in areas of folding and deformation, increases in temperature have been detected and attributed to friction developed by pressure and movement. With a long time interval this heat becomes important, as is noted on page 342.

DETERMINATION OF EFFECT OF SHEARING ON ORGANIC MATTER OF OIL SHALES

Determination of any effect shearing might have on the organic matter of oil shales, as outlined in the first of this series of papers, has been made by extraction of the sheared shale and of a representative sample of unsheared shale. The usual procedure has been to grind both shales in a porcelain or steel mortar to less than 80-mesh and to extract a given weight of undried shale in a Soxhlet extractor with either carbon tetrachloride or chloroform. Moisture determinations are made separately. The extracts obtained with chloroform are dried for two hours at 50° C. in a current of nitrogen, after which no chloroform is present. Figures are thus obtained for the percentage of soluble organic matter present in the sheared and unsheared shale.

COMPARISON OF SHEARING EXPERIMENTS WITH SHEARING IN FOLDED ROCKS

The pressures exerted in the various tests range from 36,000 to at least 100,000 pounds per square inch and correspond in amount with static pressures calculated as existing at depths in the earth ranging from 5 to 15 miles.[1]

In the tube experiments intense shearing of the shale was produced (Figs. 7 and 8), the shale failing, almost if not entirely, by fracture. This deformation is clearly far more intense than normally has occurred in the folded regions of oil fields, or even in more closely-folded mountainous regions. The shattering of the shale is more comparable with that occurring along a fault plane, especially since the deformation in both cases is accomplished rapidly or even instantaneously. Another factor, accounting in part for the intense deformation of the shale in metal tubes, and for the difference between this deformation and that

[1] F. D. Adams, *Jour. Geol.*, Vol. 20 (1912), p. 109.

in most folds of oil fields, is the relatively low containing pressure exerted by the tube on the shale. Thus, these experiments depart rather widely from natural conditions of folding, but in so far as the problem has been to determine the effect of differential movement or shearing on the organic matter of the shales, the intensifying of the shearing is well justified. Were positive results obtained, however, this difference between experimental and natural conditions would require careful interpretation before applying experimental results to natural occurrences. Further experiments in which containing pressures are still greater are now under way.

The spool-type apparatus experiments, as already indicated, permit deformation of the shale without visible fracturing, and the term "flowage" may be applied to the manner in which the shale yields, that is, by granulation and recrystallization of the mineral particles, particularly of calcite, or by gliding. Even here there is probably some minute fracturing. Exactly how the organic matter yields to stress is not definitely known. It seems probable that the finely-disseminated organic matter would act as a lubricant and permit more easy movements between the mineral grains under load. Being less competent than the mineral particles to withstand stress, the organic matter probably yields largely by flowage, as would a fluid. The so-called flowage experiments, however, are considered as duplicating more nearly the conditions of folding in sedimentary rocks relatively near the surface.

At this point it is pertinent to inquire how much deformation is accomplished by shearing in a shale bed which, for example, lies between more competent sandstones, and has been folded into an average anticline, such as occurs in an average oil field. It is well known that in such folds, fracture cleavage, to say nothing of flow cleavage, is seldom if ever developed. Jointing is one of the principal methods by which such rocks yield to stress—jointing either across, or parallel with, the beds. The lack of fracture and flow cleavage along bedding planes seems clear evidence that the differential movements in the beds are slight and are taken up by very small local displacements, and that throughout the larger part of such shale formation the amount of shearing taking place in any unit, particularly between bedding planes, may be very small.

Still another factor worth considering in this connection is the amount of heat developed by friction during such low folding movements. The common conception follows the view that since pressures and friction develop heat, therefore in folding movements considerable heat must be developed, and the amount of heat will increase with the intensity of

the deformation. Unfortunately, little experimental evidence on this point is available. This view, however, commonly loses sight of the fact that the amount of heat present at any one time depends on how quickly it is generated and how rapidly it is dissipated, and the specific heat of the rocks involved. Most folding movements are presumably extremely slow, requiring probably a long geologic age. Likewise the flow of heat through rocks[1] has been shown to require a tremendously long time, but time comparable in length with periods of folding and generation of heat. In other words, heat generated might be dissipated almost as rapidly as formed, and its effect, therefore, largely nullified. A question, therefore, may be raised here, as to what value may be assigned to the amount of heat generated in folding of moderate intensity, and as to the amount the temperature of a formation such as shale may be raised by such movements. In answering this question, it is evident that much experimentation is required. The evidence of other investigators and of the present investigation is that even with instantaneous and extreme deformation, the amount of heat generated in the shearing of shale is extremely low and insufficient to raise the temperature of the shale a significant amount.

Thiessen,[2] in discussing the effect of pressure in the formation of coal, notes, on the other hand, that "pressure is invariably accompanied by a rise in temperature" and that it is known "that rocks under high pressure and in the act of folding, or where earth movements are taking place, are at a *slightly* higher temperature than the same rocks farther remote."[3] Such a slight rise in temperature, therefore, given geologic time, may be important in converting organic matter to oil, but the effect of such heat must be distinguished from that of pressure alone.

SHEARING PRESSURE TESTS ON COLORADO OIL SHALE

Oil shale from the Green River formation (Eocene) of DeBeque, Colorado, was secured from the laboratories of the department of petroleum engineering, University of California. On retorting, the average yield of this shale is 50-55 gallons of oil per ton. It contains approximately 20 per cent of organic matter.

[1]L. R. Ingersoll and O. J. Zobel, *An Introduction to Mathematical Theory of Heat Conduction with Engineering and Geological Applications*, Ginn & Company (1913).

[2]R. Thiessen, "The Constitution of Coal," *Trans. Amer. Inst. Min. Met. Eng.* (March, 1925).

[3]M. X. Stanier, "Isogeotherms and Tectonic Geology," *Annals des Mines de Belgique Abst. Coll. Guardian* (1924), pp. 127, 415.

The various shearing pressure tests to which the shale has been subjected are listed in Table I. Data regarding time of loading and unloading, the final load[1] per square inch, and the percentages of soluble extract obtained from the sheared shale and from comparable samples of unsheared shale are given.

EFFECTS OF SHEARING COLORADO SHALE

From Table I it is evident that shearing pressures of the magnitude used (ranging from 36,400 to 104,000 pounds per square inch) caused essentially no difference in the amount of soluble organic matter present in Colorado oil shale. In all tests, the extracts were of a semi-liquid nature, and deep brown in color. Extraction of the sand used in packing shale cores in long tubes yielded negative results. In the tests, had any organic matter been changed or volatilized, it is highly probable that the original soluble constituents of the shale would be the first to alter. Since the percentages of the soluble extracts in sheared and unsheared shale show on the whole only minute differences, it is concluded that no marked volatilization occurred.

In no test was any oil formed in the sheared shale, which in appearance after shearing was as dry as before shearing, or drier. In only a few tests are the differences in percentages of extracts more than .1 per cent. Aside from Test F4, the average increase in extract, where such was obtained, is .065 per cent of the shale. The average decrease in extracts of the tests, where a decrease was found, is .092 per cent. The first four tests listed differ from the others in that carbon tetrachloride was used as a solvent, and the extracts received much more drying, to eliminate the solvent, than those in which chloroform was employed. In this prolonged drying, though both sheared and unsheared samples received the same later treatment, volatile constituents of the extract were lost to a large extent. In later tests the procedure was more standardized. Most of Colorado shales sheared in long steel tubes show a decrease in extract, but in all the "spool" flowage tests an increase in extract was obtained. The uniformity of results in the flowage tests is suggestive of a change, but the increase in yield in three tests is so small that it must be considered within the limits of experimental error. Test F4 shows a still greater increase in yield, and the longer time factor, 7 months under load, combined with the pressure, may be important. This test is being checked by two experiments in which shales are remaining under load for a year.

[1]Figures for experiments with long copper and steel tubes are for final and not necessarily greatest load.

Differences in amount of extract obtained from the shales may be caused by several factors. They may arise from original differences in the shale cores subjected to pressures, and the ends of the cores which were ground and extracted as a check. These differences may be plus or minus.

Two factors tend to increase the percentage extract from sheared shales and are indirectly related to pressure.

1. Great increase in surface of sheared shale due to intense fracturing. This would affect more the rate of solution or extraction than the amount of extract, and for a long extraction period, of 24 hours, would not be so apparent.
2. Oxidation of the insoluble organic matter of the shale during shearing (particularly where the shale yields by fracturing) may also increase the yield by converting the insoluble matter to a soluble form. Oxidation would proceed more rapidly in the finely-divided sheared shale than in the relatively coarser-ground unsheared shale, as noted in the first paper of this series.

Two factors tend to decrease the percentage of extract from the sheared shales.

1. Oxidation of the already soluble organic matter in the shales with the formation of insoluble compounds or even of carbon dioxide.
2. Oxidation of the organic matter, possibly causing the formation of a higher percentage of volatile constituents in the extracts of sheared shales. That such compounds are formed has been shown in the first paper. Loss of such volatiles while drying extracts to eliminate the solvent would decrease the yield of extract. Further discussion of this occurrence is given.

In spite of the difficulties arising in measuring accurately the extractable material of the shales when sheared and when not sheared, the differences are all so low that the conclusion may be drawn that pressures, in themselves, as great as 100,000 pounds per square inch, existing through varying periods of time, but all short compared with geologic time, and exerted constantly or intermittently through given time intervals and causing either intense shearing or flowage, have essentially no effect on the solubility of the organic matter of Colorado or similar oil shales.[1] They do not convert the organic matter to oil and probably have no effect in changing its chemical composition. It is also evident that any heat of friction developed during shearing is insufficient to cause a measurable cleavage in the organic matter through the short time intervals possible in the experiments. As noted, a slight rise in temperature due to friction and existing through geologic ages may be quantitatively important. There are as yet insufficient data to conclude that

[1]The results of shearing oil shales under still greater containing pressures may modify this conclusion slightly.

TABLE I

SUMMARY OF RESULTS OF SHEARING TESTS ON COLORADO SHALE

Test Number	Time of Shearing	Load in Pounds per Square Inch	Per Cent Extract from Sheared Shale	Per Cent Extract from Unsheared Shale	Difference in Per Cent Extract	Solvent	Remarks
Shale Sheared in Long Copper Tubes							
1 1	10 min.	40,000	1.007	1.001	+.006	CCl_4	Shale dried before extraction
2 2	5 hrs.	38,095	1.367	1.510	−.143	CCl_4	Shale dried before extraction
3 4	10 min.	45,000	1.006	1.001	+.005	CCl_4	Shale dried before extraction
4 3	100 min.	38,150	1.621	1.580	+.041	CCl_4	Not dried
5 100 C	21 min.	36,400	2.02 2.09	1.75	+.30	Chloroform	Shales not dried
Shale Sheared in Long Steel Tubes							
6 101 C	10 min.	40,200	1.81	1.85	−.04	Chloroform	Shales not dried
7 102 C	15 min.	41,600	1.87	2.18	−.31	Chloroform	Shales not dried
8 103 C	40 min.	58,000	1.95	2.02 av.	−.07	Chloroform	Shales not dried
3 6	30 min.	58,155	2.008 2.085	2.02 av.	−.01 +.06	Chloroform	Shales not dried
10 105 C	4 days	65,750 (50,000-lb. load per day)	2.29	2.28	+.01	Chloroform	Intermittent shear
11 104 C	50 min.	76,500	2.19−	2.25	−.06	Chloroform	

Powdered Shale Sheared in Short Copper Cylinders

12 115	12 min. shear 17 hrs. unloading	77,400	2.18	2.13	+.05	Chloroform	
13 117	13 min. loading 18 hrs. unloading	58,400	2.125	2.13	−.005	Chloroform	
14 116	37 min. loading 18 hrs. unloading	107,800	2.13	2.13	.00	Chloroform	" "

Rock Flowage Tests—In Spool-Piston Apparatus (Steel)

15 F1	1½ hrs.	104,000	1.98	1.94	+.04	Chloroform	
16 F2	71 days	67,800	1.985	1.94	+.045	Chloroform	Flowage, .03 inches
17 F3	109 days	67,800	1.962	1.94	+.02	Chloroform	Flowage, .045 inches
18 F4	7 mos.	67,800	2.15	1.94	+.21	Chloroform	Flowage, .045 inches

a greater (geologic) time factor combined with pressure alone would act in the same way, that is, as an aid to the generation of oil.

INCREASE OF VOLATILES INDIRECTLY DUE TO SHEARING

Though the total amount of extract obtained from sheared and unsheared Colorado shale is more or less constant, it has been found that in the extracts from sheared shales a higher percentage of volatile constituents is lost on drying at 105° C. than in the extracts from unsheared samples. This has been described in the first paper. The explanation offered for this is that shearing, in causing a tremendous increase in surface, promotes oxidation. Oxidation has been shown as the cause of the formation of soluble organic compounds from complex insoluble compounds, the change probably occurring by the splitting of long-chain unsaturated hydrocarbons at the position of the double bonds. In this way lighter molecules are formed. It is therefore possible that some such compounds of lighter molecular weight might be sufficiently light to be volatile at the drying temperatures used, depending on the position of the double bonds in the insoluble compounds. Thus the reaction may be related more to oxidation than to actual pressures. It is not to be inferred, however, that shearing in nature is necessarily or even ordinarily accompanied by oxidation, particularly where the rocks are rich in organic matter. It is admitted, furthermore, that heat of any source would have the same effect in producing lighter volatile constituents. The natural occurrence, therefore, of a high volatile content in carbonaceous rocks is not to be inferred as caused by oxidation.

In this connection the results of David White's[1] study of coals are worth consideration. Where coal beds have been sheared in the vicinity of faults or close folds, they contain a higher percentage of volatiles than coals not so deformed but which appear to have suffered either greater or longer-continued pressure without relief. This higher content of volatile constituents in rocks near sites of easy relief appears to be the reverse of the general situation, since on the whole the coals which have been subjected to the greater pressures and deformation have a higher fixed carbon and lower volatile content than coals subjected to lesser earth pressures and movements.

The fact that Colorado oil shale sheared under experimental conditions shows an increase in volatile constituents suggests a possible relation of this phenomenon to the observations of White regarding the

[1]David White, "Progressive Regional Carbonization of Coals," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 71 (1925), pp. 253-81.

higher volatile content of coals in areas where relief of pressure by faults and close folds prevailed. However, if the experimental results are caused by oxidation, indirectly related to the shearing, as postulated, no relation can be shown. Further discussion of the possible effects of pressure in promoting changes in the physical or chemical nature of organic compounds of oil shale or coals is given after the experimental results of tests on other oil shales.

SHEARING PRESSURE TEST ON COLORADO SHALE AT 105° C.

Where shearing and flowage of oil shales is brought about at high temperatures, the effect of the pressure should be measured, of course, by differences in extract obtained from the sheared or flowed shale and similar shale which has had the same heat treatment. The combined effect of a shearing pressure ranging from 67,800 to 100,000 pounds per square inch at a temperature of 105° C. for one week is to give a very small increase in the extractable matter over that obtained from shale which has received neither the pressure nor the heat treatment.

	Per Cent Extract
Shale flowed at 105° C. for 7 days and at room temperature for 62 days. Load 67,800 pounds per square inch	2.08
Original shale	1.94

Maier and Zimmerley[1] have shown that the effect of heating Utah oil shale in an evacuated sealed tube for 90 days at 100° C. was negligible, and from other data concluded that a 1 per cent conversion of insoluble organic matter to a soluble form, at 100° C., would require several thousand years. If the rate of this reaction for the organic matter of Colorado shale is of the same order of magnitude, comparison of the samples of sheared and heated shale with unsheared and unheated shale is therefore justified. The difference in these extracts is too close to the limits of experimental error to justify any conclusion that these temperatures and pressures did produce an effect.

Mechanically, the heat used in this experiment aided materially in the flowage of the shale, the resulting deformation being equivalent to that produced by a load of more than 100,000 pounds per square inch at room temperatures. It should be noticed, therefore, that the amount a rock has flowed is not under all conditions a true indication of the relative amount of pressure endured.

[1]C. G. Maier and S. R. Zimmerley, *op. cit.*, p. 77.

Experiments using higher temperatures, 150° C., for a period of 4 hours and an initial pressure of 67,000 pounds per square inch, resulted in the blowing-out of the spool type steel apparatus and the almost entire loss of the shale.

Further experiments in this phase of the work are being undertaken. Many difficulties are presented not only in technique but also in the interpretation of results. Leslie[1] has indicated the difficulty of distinguishing the effect of pressure from the influence of heat and time on the reactions of hydrocarbons when all are combined. He says:

> If pressure has an effect on the reactions at all, it would influence the volume, and hence the time factor, and only by a series of approximations can experimental conditions be adjusted so that the time factor in all cases would be the same, and the effect of pressure, as such, be ascertained.

Shearing pressure experiments have been conducted by Van Tuyl[2] on oil shale at temperatures of 100° and 215° C. His results indicate that little effect was produced on the organic matter of the shales. He noted, however, that when flowed and unflowed shales were subjected to later heat treatment in open pyrex tubes at a temperature of 340-365° C., the soluble extract from the flowed Ashland, Ohio, shale was consistently less than from the unflowed shale. Since Maier and Zimmerley[3] have shown the impossibility of securing accurate quantitative results in converting the organic matter of oil shales to "bitumen" when the heating is done in open tubes, because volatiles are lost, Van Tuyl's results must be questioned. It has been noted already that shearing pressures, probably by indirectly aiding oxidation of the organic matter, cause an increase in the volatile content of Colorado oil shale. Subsequent heating of such a sheared shale in an open tube would naturally result in the loss of these volatiles and a lower percentage recovery of soluble extract than would be secured from an unsheared shale.

AUSTRALIAN "KEROSENE" SHALE

A block of Australian "kerosene" shale was obtained from the petroleum engineering department of the University of California. The shale, on destructive distillation, yielded 137 gallons of light brown oil per ton. Extraction with chloroform in a Soxhlet extractor yields approximately 1.5 per cent of soluble matter after 24 hours and there-

[1] E. H. Leslie, *Motor Fuels* (New York, 1923), pp. 321 *et seq.*

[2] F. M. Van Tuyl, *op. cit.*

[3] C. G. Maier and S. R. Zimmerley, *op. cit.*

after very low amounts. The extraction curve is similar to those of other typical oil shales and indicates a limited solubility of the organic matter. The soluble extract colors the solvent a very dark brownish-black. It is a dark semi-liquid and contains a considerable amount of rather volatile constituents which are difficult to retain on evaporating the solvent at 50° C. Loss of these volatiles continues on drying at this temperature even after no trace of the halogen solvent can be detected.

Shearing pressure tests similar to those used for the Colorado shale have been made on this shale. The results of these are shown in Table II. In no test was any oil generated by the shearing pressure. Differences in amount of extractable material from sheared and unsheared shales are slight and within the limits of experimental error. In six out of eight of the tests, slightly greater amounts of extract were obtained from the sheared than from the unsheared shale, but since there are factors other than pressure, as mentioned in the test of the Colorado shale,

TABLE II

SUMMARY OF RESULTS OF SHEARING TESTS ON AUSTRALIAN KEROSENE SHALE
EXTRACTION—24 HOURS WITH CHLOROFORM

Number	*Test Number*	*Time (Minutes)*	*Total (Final) Load*	*Pounds per Square Inch*	*Per Cent Extract from Sheared Shale*	*Per Cent Extract from Unsheared Shale*	*Difference*
			Cores Sheared in Steel Tubes				
1	201	40	56,000 25 min. 150,000 15 min.	50,300	1.01	1.29	−.28
2	202	22	150,000	40,200	1.35	1.01	+.34
3	203	3 2	100,000 176,000	44,000			
			Shale <6-Mesh—Sheared Between Steel Plates				
4	200*A*	12	300,000, in copper cylinder	67,700	1.604	1.53	+.07
5	204*A*	15	400,000, in copper cylinder	81,500	1.585	1.53	+.055
6	205*A*	15	400,000, no lateral support	56,600	1.602	1.53	+.07
7	206*A*	15	400,000, no lateral support	81,500	1.55	1.53	+.02
			Flowage Test—Room Temperature				
8	F.I.A.	30	47,000	106,000	1.10	1.03	+.07

which might account for a small increase in yield, it is not safe to attach much if any importance to these results.

KENTUCKY OIL SHALE

A sample of Chattanooga (Upper Devonian) oil shale was collected by Daniel J. Jones, of the Eastern Gulf Company, at Berea, Madison County, Kentucky, about ¼ mile from the outcrop and probably 25 feet above the Corniferous lime. The Corniferous at Berea is fairly well saturated with petroleum, small cavities and geodes being filled with oil.

The sample used for shearing-pressure tests was thin-bedded and somewhat fissile. Its thin-bedded character and lack of coherence prevented the securing of solid drill cores. An average sample of the shale on destructive distillation yielded 15 gallons of oil per ton. This is close to the average yield of the shale determined by W. R. Jillson as approximately 16 gallons of oil per ton, though further analyses have raised this figure to 20 gallons per ton.[1] Extraction of the shale with chloroform for 24 hours yields 0.63 per cent soluble extract, and for 96 hours, 0.76 per cent. The extraction curve (Fig. 1 in the first paper) is similar to those for other shales in showing a limited solubility of the organic matter.

Two shearing pressure tests on this shale were made. The shale was ground to less than 6-mesh and packed tightly in the center of 7-inch steel tubes with sand packing at either end. The shearing was done in the same manner as for the Colorado shales.

After shearing, the shale was removed from the tubes and ground to less than 80-mesh in a steel mortar, as was a representative sample of unsheared shale. Extraction was made with chloroform for a period of 24 hours. The results are shown in Table III.

TABLE III

RESULTS OF SHEARING TESTS ON CHATTANOOGA OIL SHALE, KENTUCKY

Test Number	*Time*	*Total Load*	*Pounds per Inch*	*Per Cent Sheared Shale*	*Extract Unsheared Shale*	*Difference*
302	20 min. loading 48 hrs. unloading	200,000	87,000	0.688	0.63	+0.058
303	25 min. loading 30 min. unloading	250,000	81,700	0.65	0.63	+0.02

In Table III, the differences in extract obtained from sheared and unsheared shale are within the limits of experimental error. Shearing

[1] "Oil Shales of Kentucky," *Kentucky Geol. Survey* (1925), p. 62.

pressures on the ground shale first compacted the shale, and then deformed it considerably by the development of shear planes throughout the shale. Although the amount of work done on these specimens is not as great as that accomplished on some solid cores of other shales, the final loads per square inch are comparable. The shearing appears to have had no effect on the solubility of the organic matter, and certainly has not caused the formation of oil.

CLEVELAND, OHIO, DEVONIAN OIL SHALE

A large sample of shale from the basal member of the Cleveland formation was secured through the kindness of J. E. Hyde, Western Reserve University, and C. U. Hendershot, superintendent of the Cleveland Brick and Clay Company. The sample is dark gray, and occurs in beds of medium (½- to 1-foot) thickness. On destructive distillation, it yields 5 gallons of oil per ton. Extraction with chloroform for 24 hours yields 0.25 per cent soluble matter. The extract is a brown semi-liquid and corresponds closely in physical properties with the extracts from the Colorado shales.

Only one shearing-pressure test has been completed on this shale. This was carried out in the same manner as those of the Kentucky shales, with ground shale, in a steel tube. A total load of 200,000 pounds was applied in 20 minutes and the shale was left under load for 48 hours. The final load exerted was 66,000 pounds per square inch (Fig. 4). The shale was then ground to less than 80-mesh and extracted with chloroform for 24 hours, as was a sample of the unsheared shale. The results of extraction are as follows:

	Per Cent Extract
Sheared shale	0.24
Unsheared shale	0.25

Here, again, shearing pressures failed to influence the solubility of the organic matter in the shale. It might be argued that little effect would be expected in this shale on account of the low content of organic matter. On the other hand, with such a high mineral content, it is probable that the disseminated organic matter was subjected to more friction during shearing and grinding of the mineral grains together than shales with a very high organic content. In spite of this, however, no change was detected.

PRESSURE TESTS ON COLORADO OIL SHALE WITH CATALYSTS AND SOLUTIONS

Ground Colorado shale, less than 14- or less than 80-mesh, has been subjected to shearing pressures in the same manner as the solid cores of shale. Shale has been mixed with fuller's earth, anhydrous aluminum chloride, and solutions of potassium hydroxide and sodium chloride. The details of these experiments are given as follows.

FULLER'S EARTH OR LLOYD'S REAGENT

A mixture of Colorado shale (of less than 80-mesh size) and 21 per cent dried fuller's earth was placed in a short (1½-inch) copper cylinder and inserted on end between two steel plates. A total load of 250,000 pounds was applied in 25 minutes. The deformed specimen was left under load for 3 hours and was then removed, the load having fallen in that time to 150,000 pounds. The result of the pressure was to deform the cylinder into a circular disc, ¼ inch thick and approximately 2 inches in diameter. The load per square inch was approximately 79,500 pounds. The shale was now quite firm and dry, though rather easily powdered with a hammer. Extraction of the sheared specimen gave an extract of 1.79 per cent of the shale used. The average extract of the same shale not sheared or mixed with fuller's earth was 2.13 per cent.

Other tests were made using a more highly adsorptive fuller's earth (Lloyd's reagent) and crushing it in the same way, but in a steel cylinder. The shale was mixed with 26 per cent of this reagent. The load in this test was the same, 250,000 pounds; time of loading, 15 minutes; and of unloading, 10 minutes. The final load per square inch was 77,400 pounds.

Extraction results were as follows.

	Per Cent Extract		
	Per Cent of Mixture	*Per Cent of Shale Alone*	*Per Cent of Shale not mixed with Reagent*
From sheared shale	1.28	1.73	
From unsheared shale	1.22	1.65	2.13

In both tests a smaller extract was obtained from the mixture of shale and fuller's earth than from the shale alone. While the decrease is not great, it suggests that some of the soluble constituents of the

shale are adsorbed by the kaolin firmly enough to resist solution. This reagent clearly has no effect in producing more soluble material.

ANHYDROUS ALUMINUM CHLORIDE

Powdered Colorado shale (80-mesh) was mixed with 40 per cent anhydrous aluminum chloride and sheared in a short copper cylinder with a load of 250,000 pounds in 15 minutes. The specimen was left under load for 1 day. The final load was 79,600 pounds per square inch. The mixture after pressure was firm, hard, and darker in color than before. On removing the shale, flattened cones broke out from the top and bottom of the disc. The sample was then broken fine, and washed with water to remove the aluminum chloride, and dried slowly at 50° C. for 3 days. Addition of water caused the formation of hydrochloric acid, which immediately attacked the carbonates present.

Extraction of the residue yielded 2.93 per cent soluble matter, figured on the original weight of shale used. The shale from which the sample was taken gives an average of 2.13 per cent soluble matter. The increase in extract in the sheared mixture is to be explained, probably, by some catalytic effect of the aluminum chloride. As noted in the first paper this reagent causes a marked increase in yield of extract[1] when placed with the shale during extraction, and it is probable that the effect produced is independent of shearing pressures exerted.

POTASSIUM HYDROXIDE SOLUTION

Colorado shale ground to less than 14-mesh was packed in a long steel tube and saturated with a $\frac{1}{5}$ normal solution of potassium hydroxide. Sand was placed at either end of the shale, as in the solid shale-core experiments. A load of 150,000 pounds was then applied on the shale in 30 minutes, and the specimen was allowed to stand in the pressure machine for 24 hours, when the load had dropped to 50,000 pounds. The tube of shale was deformed from its circular section to an elliptical section, the maximum load per square inch amounting to approximately 55,000 pounds. During the shearing some of the solution, but no oil, was squeezed out of the shale into the sand. When removed from the steel core, one-half was extracted after drying 24 hours at room temperature, and the other half was first washed free of the alkali, dried at 50° C. for 24 hours, and then extracted. The extracts obtained are essentially the same in amount.

[1]Recent tests on Colorado and Australian shale with anhydrous aluminum chloride show that the effect of the reagent is not regular. A mixture of 5 per cent chloride gives a greater increase in yield than a 10 per cent mixture. With the latter a greenish-gray solid product is obtained by extraction.

	Per Cent Extract in 24 Hours
Natural shale < 14-mesh, not sheared or treated with alkaline solution	2.13
Sheared shale, extracted with *KOH* present	2.20
Sheared shale extracted after leaching out *KOH*	2.06

SODIUM CHLORIDE SOLUTION

Powdered Colorado shale of less than 14-mesh size was saturated with an 8 per cent sodium chloride solution and subjected to shearing pressures as previously described. The load exerted was 150,000 pounds.

The results of extraction on the sheared shales are as follows.

	Per Cent Extract with Chloroform
Natural shale, not sheared	2.13
Sheared shale, plus salt solution	2.24
Sheared shale, leached of salt	2.00

In summary, shearing tests of Colorado oil shale, with various catalytic agents present, show that anhydrous aluminum chloride increases slightly the percentage of extractable material. Adsorbents like fuller's earth decrease the yield, and solutions of potassium hydroxide and sodium chloride have little or no effect. In the test with aluminum chloride, the increase in extractable matter is probably due to a chemical reaction not necessarily related to the shearing pressures, since extraction of a mixture of shale and this compound gives a still higher yield. The fuller's earth, or kaolin, seems to adsorb some of the already soluble organic matter and so decrease the yield on extraction, whether shearing pressures are exerted or not.

SHEARING-PRESSURE TESTS ON COLORADO SHALE WITH ORGANIC SOLVENTS PRESENT

Experiments have been carried out with ground Colorado shale of less than 14- and 80-mesh, similar to those in which solutions of alkali and salt were used, but with organic solvents present such as chloroform and petroleum ether. The shale in each test was saturated with the solvent. Sand was placed on either end of the shale, which was packed in the center of a 7-inch steel tube. In all tests the solvent used dissolved some organic matter and migrated (under load) from the shale into the sand, in some tests even leaking out of the brass caps at the ends of the tubes.

The purpose of these tests was to determine whether the solvents under pressure would dissolve more organic matter, and if they would migrate with the dissolved material into the sand, and to what extent. The results are shown in Table IV.

TABLE IV

RESULTS OF SHEARING TESTS ON COLORADO SHALE WITH ORGANIC SOLVENTS PRESENT

Test Number	*Load*	*Load per Square Inch*	*Time*	*Per Cent Extract*				
				From Shale	*From Sand*	*Total*	*Original*	*Solvent*
110C	90,000		8 min.	1.501	.298 +loss?	1.80	2.12	$CHCl_3$
123	450,000	53,500	30 min. +65 hrs. unloading	3.51	.25	3.76	2.13	Petroleum ether
127	150,000	54,500	30 min. +72 hrs.	1.76	.21	1.97	2.20	Petroleum ether

The results of extraction are too variable to be of much significance. In two tests less soluble matter was obtained from the sheared shale and sand than from the original shale, and in the third test the reverse was true. In all tests a relatively small amount of dissolved "bitumen" was squeezed from the shale into the adjoining sands. This migration of "bitumen" and solvent seems clearly due to the fact that the powdered shale used had a porosity greater than in the solid state. Shearing pressures at first tended to decrease this porosity by compacting, and at this time the solvents would be expelled until a minimum porosity was obtained. Thereafter, shearing pressures would increase the volume of the cores, and this might even cause a return of some of the liquid, but further expulsion of solvent and dissolved material would not occur.

PRESSURE TESTS ON SHALES AND KAOLIN CONTAINING OIL AND "BITUMEN"

Shearing pressure tests have been made on a California (Santa Maria) shale containing approximately 44 per cent of oil by weight, and on several artificial mixtures of oil in kaolin and "bitumen" in fuller's earth. The purpose of these tests was to determine whether oil or the

"bitumen" could be squeezed from the shales or kaolin by shearing pressures.

In the pressure tests on shale cores, it has been noted that after shearing many open fractures were formed, and that the net result of the deformation was increase in volume. W. J. Mead[1] has demonstrated that, in the deformation of a solid body in which the mineral grains are arranged in close packing and do not yield by flowage or comminution, an increase in pore space must take place. The average oil shales, therefore, evidently have not sufficient soft organic matter present in them to prevent their being "dilatant" or to allow them to flow as a fluid, when the containing pressures are low. Under such conditions it is clear no oily matter could be squeezed out from the shale.

When sufficient organic matter, oil or "bitumen," is present, however, so that the shale will deform as a fluid, by flowage, can the oil or "bitumen" be eliminated to any extent by shearing pressures? In the flowage tests with Colorado and Australian shales, previously mentioned, no organic matter was squeezed from the shale. In the tests in which organic solvents were added to ground shale, some of the solvent and dissolved "bitumen" were pressed from the shale, but in these the total volume of liquid in the pores was very high and the packing of grains was loose. Furthermore, the fluidity of the solvent and solute was high compared with a heavy oil or "bitumen."

Shale from Santa Maria, California, was packed solidly in the central part of a steel tube with sand at both ends, and deformed, as were solid cores of oil shale. A total load of 250,000 pounds was applied. The final load was 50,000 pounds per square inch. The shale yielded to deformation by flowage; no fractures were apparent. After shearing, the shale and sand were removed from the steel tube and extracted with chloroform separately. The sand had a slight odor of oil. The extraction results are as follows:

	Per Cent Extract
Original shale	43.68 in 48 hours
Sheared shale	42.39 in 72 hours
Sand	0.30

A mixture of kaolin with 25 per cent oil was crushed between two steel plates with a load of 250,000 pounds. No oil was squeezed from the

[1] W. J. Mead, "The Geologic Rôle of Dilatancy," *Jour. Geol.*, Vol. 33 (1925), p. 685.

kaolin. Extraction of some of the original mixture and of the sheared sample gave the following:

	Per Cent Extract
Original mixture	25.53
Sheared mixture	24.88

Fuller's earth was mixed with a sample of "bitumen" extracted from Colorado shale. Thorough mixing was accomplished by dissolving the bitumen in chloroform and stirring this dilute "bitumen" into the earth until the chloroform was evaporated. This mixture was then placed in a 1½-inch copper cylinder and sheared with a total load of 300,000 pounds, by which the cylinder was flattened to a narrow disc. No "bitumen" was squeezed from the fuller's earth, nor was any concentrated in any part of the sample. The product obtained was fairly compact, and resembled Colorado oil shale greatly in having a distinct rubbery appearance. On extraction of the original mixture, 11.05 per cent "bitumen" was obtained, and from the sheared mixture, only 9.75 per cent.

The results of all the above tests agree in that less oil or "bitumen" was extractable from the sheared shale or kaolin than from the unsheared samples in a given time. The results of shearing the natural shale with such a high percentage of oil indicates that negligible amounts of oil are squeezed from the shale, and that the oil left is held or adsorbed more firmly than ever by the shale minerals. Shearing pressures, therefore, even if they did in any way aid in the formation of oil from the organic matter of oil shales, would not materially aid in expelling it from the shales into adjacent sands. Heat, which will volatilize the oil, is the agent that seems most capable of accomplishing this.

Theoretical Considerations of Pressure and Reactions of Hydrocarbons

The geologic evidence as presented by White[1] has shown a marked relation between the amount of earth pressures (intensity of pressure or duration) and the degree of carbonization of coals. In general, devolatilization of coals has progressed with increase in pressures to which the coals have been subjected. This relation implies that shearing pressures have in some way favored the reactions in which complex hydrocarbons

[1]David White, "Progressive Regional Carbonization of Coals," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 71 (1925).

break down to simpler compounds with the generation and loss of volatile constituents and the retention of increasing amounts of fixed carbon.

Theoretically, from a physico-chemical point of view, pressure in relation to chemical reactions is considered as more or less hydrostatic. It may affect reactions directly, or inversely, or not at all. The complexity of the carbonaceous matter in coals or oil shales has so far hindered the accurate determination of the effect of pressure on the rate of reactions of this kind. Were the carbonaceous material a single definite chemical compound and the reactions of one kind, the problem would probably not exist, but when many different compounds are present, and when many complex reactions may occur under the influence of heat, the determination of the mass effect of pressure is not so simple. A start in this direction has been made by Maier and Zimmerley,[1] in determining the rate at which the organic material in Utah oil shale changes to "bitumen." These writers have shown that the rate is a function of the time and temperature to which the shale is subjected. From their results it has been suggested that the mass reaction is of the type which is not affected by pressure. Further investigation of this subject is being carried on by A. J. Carlson, at the University of California, and in conjunction with him the present investigators made several experiments to test the effect of gaseous pressures on Colorado shale. Conclusions, however, can not yet be drawn.

Earth pressures exerted on rocks are more complex than simple hydrostatic gaseous pressures, and before relating chemical changes to them it is necessary to analyze the various physical conditions which may be set up by such pressures.

R. Thiessen,[2] as already noted, states that pressure is invariably accompanied by a rise in temperature, and in so far as even a rise in temperature of only a few degrees is accomplished, given geologic ages, marked reactions may take place, yielding marked differences in the resulting products. The effect of pressure, therefore, would be indirect, yet the end products of the reactions might appear related directly to the amount of pressure.

Pressures are known to promote or favor reactions where the volume of the products of the reaction are smaller than the original. The reactions supposed to take place in the devolatilization of coal, or in the generation of oil from organic matter of oil shales, do not appear to be

[1] C. G. Maier and S. R. Zimmerley, *op. cit.*

[2] R. Thiessen, "Constitution of Coal," *Mining and Metallurgy* (March, 1925).

of this type, since the total volume of the end products is greater than the original. With such reactions, if pressure is a factor at all, decrease of pressure should aid them. The following is an attempt to show that in the deformation of rocks by earth pressures a decrease in fluid pressures is possible.

Recent studies of "dilatancy" by W. J. Mead[1] have shown that where the deformation of a solid aggregate occurs without the individual particles changing their shape, the deformation requires an increase in volume. In most rocks which fail by both fracture and flowage, an increase in volume is probable, but of course there may be a complete gradation from increase in volume, first to constant volume, then to an actual decrease in volume, depending on the degree of flowage. In so far as an increase in volume occurs in the deformation of rocks, fluid pressures must be locally reduced by the creation of a partial vacuum. Such a reduction of fluid pressure, therefore, would aid in changing the phase of a substance from solid to liquid or from liquid to gas. Whether it would promote chemical changes as well as physical remains to be proved. In this way, however, effects might be produced which are due mainly to reduction of fluid pressures by deformation and increase in volume. Since the increase in volume may be related to the amount of fracturing in the rocks, and the fracturing in turn to the intensity or duration of earth pressures exerted, any resulting physical or chemical changes in the organic compounds would appear more or less related to the earth pressures. Investigation of this possibility seems worthy of consideration.

Johnston and Niggli,[2] in discussing the general effect of non-uniform or shearing stresses on rocks in relation to the observed chemical changes which they undergo during dynamic metamorphism, make practically the same point, that unequal pressure acts on the solid phase but not on the liquid phase, or not to the same extent on the liquid phase. The effect on the solid phase is always to lower the melting point of a substance (or raise the vapor pressure and hence its solubility), and by an amount which is many times as great as the effect produced by the same pressure acting on both phases simultaneously. Or, again, the action of unequal pressures on the solid phase increases the "activity" of that phase, or its tendency to pass over to another phase. Here once more,

[1]W. J. Mead, "The Geologic Rôle of Dilatancy," *Jour. Geol.*, Vol. 33 (1925), p. 685.

[2]J. Johnston and P. Niggli, "Principles Underlying Metamorphic Processes," *Jour. Geol.*, Vol. 21 (1913), pp. 600 *et seq.*

it may be repeated, the emphasis is placed on change in physical rather than chemical state.

In summary: if pressure be found to have an effect on the chemical reactions of hydrocarbons such as occur in oil shales or coals, in relating the effect of this pressure to natural occurrences, the opposite effects of hydrostatic pressure and relief of pressure following increase in volume must be considered.

Summary and Conclusions

Summary of shearing pressure tests

Shearing pressure tests on oil shales from Colorado, Australia, Kentucky, and Ohio, conducted at room temperatures, have all failed to generate any oil in these shales and have not changed the amount of extractable matter to any measurable extent. The pressures exerted ranged from 38,000 to more than 100,000 pounds per square inch. The shales yielded by either fracture or flowage, or both. The deformation was rapid in some tests, and slow in others, one test being continued for 7 months. The loads applied were of the nature of intermittent shears, with the time varying from a minute to a day. In no case was the heat of friction developed during shearing sufficient to be measured, and the negative results of the tests show that the amount of this heat was never great enough.

One effect of shearing pressures on Colorado shale noticed is the increase in volatile constituents over that in unsheared shale. This was detected on drying the extracts at 105° C. The cause of this increase is thought to be oxidation of some of the organic matter during the intense fracturing of the shale, and since oxidation would probably not occur in the shearing of covered carbonaceous rocks in nature, the results are not applicable to natural occurrences.

A shearing pressure test on Colorado shale at 105° C. for 7 days caused a slightly higher yield of soluble organic matter than was obtained from unheated and unsheared shale. The difference is, however, within the limits of experimental error. Further experiments are being made on oil shales which are sheared at elevated temperatures. This involves the solving simultaneously of four variables: (1) the shearing pressure, (2) the temperature, (3) the gas pressure developed, and (4) time. A fifth variable is heat of chemical reactions which may take place.

Colorado shale mixed with possible catalytic agents such as fuller's earth, potassium hydroxide, or sodium chloride solutions, was subjected to high shearing pressures without increasing the solubility of the organic

matter. Anhydrous aluminum chloride, when mixed with oil shale and sheared, causes a small increase in yield of extract. This effect can be produced by extracting shale mixed with aluminum chloride, and is probably related to a chemical reaction, rather than to any pressure exerted on the shale. When organic solvents are placed with oil shale and the shale sheared, some of the solvent and dissolved "bitumen" migrate to adjoining sands. In one test the oil shale, after such treatment, gave a greater yield of extract than formerly, in spite of a loss of dissolved "bitumen."

Shearing pressures exerted on a shale containing 44 per cent infiltrated oil failed to squeeze out more than .6 per cent of the oil. The pressures had the further effect of decreasing the rate of solution of the oil contained in the shale. Similar results were obtained by shearing artificial mixtures of kaolinite and oil or fuller's earth and "bitumen."

Shearing pressures, of themselves, when exerted on oil shales at low (room) temperatures and through relatively short periods of time, do not generate oil from the organic matter, and even if they did, would not aid in the squeezing-out of this oil into adjoining sands, but rather would hinder any such movement.

Shearing pressures, in so far as they cause an increase in volume of the deformed rock and thereby a reduction of fluid pressures, may be related to the change in phase of organic compounds in such rocks as oil shales. So far no experimental results have been obtained to prove this. It is possible that this factor, together with heat of one source or another and geologic time, may modify considerably the preceding conclusion.

CONCLUSIONS AS TO RELATIVE IMPORTANCE OF SHEARING PRESSURES AND HEAT IN THE GENERATION OF OIL FROM OIL SHALES

The negative results of the shearing pressure tests so far made have some significance. The pressures exerted in most cases were relatively high, and equal to static pressures existing at depths in the earth ranging from 10 to 15 miles.[1] The deformation and shearing of the shales was for the most part far greater than that produced in shales which have undergone open folding. The heat generated by shearing was not sufficient to cause measurable changes in the organic matter of the shales. A conclusion which may be safely drawn, therefore, is that where oil shales are folded at shallow depths, where earth temperatures are less than 100° C., little change will occur. If any change does take place, through

[1]Frank D. Adams, *Jour. Geol.*, Vol. 20 (1912), p. 109.

long periods of time, this may be explained and attributed to the effect of the temperature rather than to the pressure.

Where, however, oil shales have been deeply buried, as in geosynclines, the higher temperatures existing below 10,000 feet will probably be sufficient in themselves to cause the slow distillation of the organic matter to oil and gas. Maier and Zimmerley have shown that the formation of pyrobitumens (and oil and gas) from Utah shale is a function of both time and temperature. For a 1 per cent conversion to occur at 100° C. would require 840,000 years.

Considered geologically, this time is relatively short, and it is clear a much greater conversion might occur during periods reckoned in millions of years. At still higher temperatures, attainable at greater depths, the rate of conversion would increase rapidly.

Adams[1] has calculated the probable average temperatures existing within the earth at various depths. They are as follows:

Depth	*Temperature*
5 kilometers (16,404 feet)	150° C.
10 kilometers (32,808 feet)	260° C.
15 kilometers (49,212 feet)	375° C.

Van Orstrand,[2] in a recent paper on the temperature in the world's deepest wells, shows actual and estimated temperatures. Those estimated at a depth of 10,000 feet range from 189.8 to 537.1° F., several having temperatures close to the boiling point of water.

From these figures it is evident that oil shales buried to any depth below 10,000 feet would tend to be destructively distilled in the course of time, with the production of oil and gas. The question here arises, what would be the influence of pressure on these reactions? Would pressure increase or decrease their speed, or would it have no effect at all?

In this connection some writers have compared the supposed effect of pressure and temperature on oil shales with the cracking process used in the distillation of oils. The propriety of the comparison may be questioned, since in studying oil shales we are dealing, not with oil, but with complex organic compounds of which we know little. Assuming, how-

[1]L. H. Adams, "Temperatures at Moderate Depths Within the Earth," *Wash. Acad. Sci.*, Vol. 14 (1924), No. 20.

[2]C. E. Van Orstrand, "Temperature in World's Deepest Wells," *Oil and Gas Journal* (April 19, 1928), pp. 39, 152, and 153.

ever, little difference in the way the two substances would behave under these conditions, it is interesting to notice the remarks of Leslie[1] on the effect of pressure on the thermal reaction of hydrocarbons.

This writer first shows that for a reversible reaction the effect of pressure will be to "favor the reactions resulting in the combination of several molecules into fewer molecules," an influence opposite to that sought in this problem.

Regarding the influence of pressure in the cracking process, however, he says:

> In the liquid phase (cracking) process, the application of pressure serves a somewhat different purpose, namely that of keeping the hydrocarbon oil in the still or reaction vessel. In order to rapidly volatilize the oil to be cracked, the vapor tension of the volatile components of the oil must equal the vapor pressure of these components of the vapor phase. The application of pressure therefore allows the use of higher temperatures in the still, and in this manner distillates of moderate volatility such as gas oil can be held in the reaction vessel at temperatures of 650° to 750° F. by pressures of only 75 to 80 pounds per square inch. The writer is of *the opinion that the effect of pressure per se, on the course of the reactions in the body of the liquid, in the vapor above the liquid, or in the condenser, is negligible.*

From the foregoing it seems most probable that temperature is by far the most important agent in promoting the conversion of bituminous material in rocks to oil. Deep burial of such rocks as oil shale attended by a rise in temperature, therefore, may be quite sufficient to change appreciable amounts of organic matter into petroleum. Any other factors causing heat must also be important, but pressure alone seems of very little importance quantitatively.

[1]E. H. Leslie, *Motor Fuels* (New York, 1923), p. 321.

SHALE-GAS INDUSTRY OF EASTERN KANSAS[1]

HOMER H. CHARLES[2] AND JAMES H. PAGE[2]
Tulsa, Oklahoma

ABSTRACT

Natural gas from carbonaceous shales is now produced in eastern Kansas, where sand gas alone formerly furnished the supply. The wells have an average initial volume of 40,000 cubic feet, and the gas is almost invariably accompanied by salt water. In this paper, the writers describe the shales in which the gas occurs, give composition of the gas, and discuss its probable source and the reasons for the variation in open flow. The drilling, equipping, and operating of the wells are also described. The regulation of the line pressure against which the wells feed is the chief operating problem. Shale wells show a decline in production, which generally is very gradual. The industry owes its existence to the excellent industrial and domestic markets throughout the gas-bearing areas.

INTRODUCTION[3]

The shale-gas industry of eastern Kansas is the result of the depletion of the sand-gas reserves of that area. A good market for the gas, the unique feature of the wells whereby as much as 70 per cent of the open flow may be taken without injuring them, their slow decline and promise of long life, the low cost of operation, and the extremely small percentage of dry holes make this industry profitable, especially to those who drill their own wells and manage their own properties.

The presence of shale gas in eastern Kansas has been known since drilling for oil and gas began many years ago. Because of the small volumes encountered and the accompanying troublesome salt water, shale gas was not then considered of commercial value. Changed economic conditions since have made it worth producing.

The history of the industry dates back only to 1921, when the first shale wells were completed in the southwest Chanute district. A few shale wells had been producing previously, notably at Cherryvale, where homes were supplied by private lines. About 1910 a shale well near Chanute was put on the line after a patented device to separate the gas and salt water had been installed by the owner. However,

[1]Manuscript received by the editor, January 31, 1929.

[2]Geologists, Oklahoma Natural Gas Corporation.

[3]The writers wish to acknowledge the benefit of suggestions made by John L. Rich.

concerted effort to produce shale gas did not begin until 8 years ago, and the most active drilling for it has taken place since 1924. Now, hundreds of wells, marked by the vertical drips at the well mouths, are scattered through eastern Kansas, and are helping to take the place of the large sand wells of former years.

The areas in which shale gas is known to occur are shown in Figure 1. Most of them have pipe-line connections. The territory southwest of Chanute is the oldest producing area. Activity spread from there through the Altoona-Neodesha district and in the vicinity of Independ-

FIG. 1.—Outline map of eastern Kansas and adjoining territory showing areas in which shale gas occurs.

ence and Cherryvale. Shale wells are found north of Coffeyville and south of that city in Oklahoma. The latest drilling has taken place in the Paola district in Johnson and Miami counties, Kansas, and in Jackson and Cass counties, Missouri.

SOURCE OF THE GAS

The most widespread strata that furnish the gas are black, highly carbonaceous shales, ranging from 3 to 12 feet in thickness, both immediately above and beneath the lowest limestone of the Fort Scott member of the Marmaton formation. This lowest limestone maintains a remarkably constant thickness of approximately 5 feet in the southeastern part of Kansas, and is invariably designated as the "5-foot lime" by drillers and operators. Above the black shale overlying the "5-foot lime" is an upper limestone member of the Fort Scott. It is designated as the "20-foot lime" because of its rather uniform thickness. The black shale beneath the "5-foot lime" gives up the greater amount of gas. Although all the strata between the base of the Fort Scott and the top of the "Mississippi lime" are now classified as of Cherokee age, it seems justifiable, on the basis of their lithologic similarity, to consider the black, gas-producing shale at the top of the Cherokee formation as a part of the Fort Scott. The Fort Scott beds range from 650 to 850 feet in depth in the Chanute-Coffeyville area, but only from 400 to 550 feet between Paola and Kansas City.

In scattered areas in eastern Kansas, gas has been encountered in the Galesburg and Ladore shales of the Kansas City formation. Other gas-bearing shales occur locally at depths ranging from 50 to 200 feet below the top of the Cherokee formation. The shales adjacent to the lower Fort Scott limestone bed produce practically all of the eastern Kansas shale gas.

The "Fort Scott" shales, where gas-bearing, are hard, brittle, and carbonaceous, and have a dull, sooty appearance on fresh surfaces. Their color is characteristically coal-black, and they give a dark brown streak. The preponderance of rather thin, flat fragments in the drill cuttings indicates that the rock has lamination common to all shales. However, the wavy conchoidal surfaces of the fragments show that the bedding is poorly developed and that the shale is not readily susceptible to parting. The few smooth surfaces at right angles to the bedding are probably joint or fracture planes. The drill cuttings from different wells vary also in size and shape, and these reveal the local differences in hardness and structure of the shale beds.

ORIGIN AND COMPOSITION OF THE GAS

Any theory that shale gas had an origin different from that of sand gas does not seem justified. Although the shale gas of eastern Kansas differs somewhat from sand gas of the same area in chemical composition and heating value (Table I), its distinguishing difference, in the opinion of the writers, is its occurrence in reservoir rock of a different type—probably rock in which it was generated. Such a black carbonaceous shale seems ideal as a source bed for the gas. The light shale or dense gray limestones above and below the gas-bearing strata give no evidence of being source rocks. Some people hold the view that the gas owes its origin to chemical action between the salt water almost invariably associated with the black shale and the shale itself, the effect being similar to that produced by the action of water on calcium carbide. Such an idea is unwarranted in view of the supposed reagents. Certain well owners insist that the long life and slow decline of the shale wells can be accounted for only by a constant generation of the gas. A current belief among some that the salt water brought to the surface by the gas is returned to the well to bring about the formation of more gas by its action on the shale is without basis because the water is prevented from reaching the shale again by a packer. Furthermore, some of the gas shale in the Paola district and some in the vicinity of Erie yield no water, and in parts of eastern Kansas the Fort Scott shales contain salt water but no gas. Technical workers maintain that the long life and slow decline of the wells can be explained by the nature of the reservoir rock—that the gas feeds into the wells very slowly from the pores and fractures within which it is stored and is retarded further by slow migration through the spaces between the laminae. Probably the gas is in solution with the salt water. A certain amount of water must be given up by the shales to yield a certain amount of gas. Even so, the dense rock gives up its content very slowly, thus extending the productive period much longer than that of a sandstone reservoir.

A comparison of the composition of shale gas and of sand gas from eastern Kansas is shown in Table I. Only a trace of natural gasoline is present in shale gas. A sample taken at the Chanute city gate, gas supplied chiefly from shale wells, had a gasoline content of only 5.24 gallons per 1,000,000 cubic feet.

INITIAL PRODUCTION

Shale-gas wells have a wide variation in volume. The smallest wells saved may test as little as 10,000 cubic feet per day; the largest, 900,000

TABLE I

ANALYSES OF SHALE GAS AND SAND GAS*

Source of Sample	*Methane* (CH_4)	*Ethane* (C_2H_6)	*Carbon Dioxide* (CO_2)	*Nitrogen* (N_2)	*Heating Value B. T. U.*	*Specific Gravity*
Colony field, Anderson Co., Kansas**	97.2	1.8	1.0	None	1,012	.5713
Blue Mound field, Linn Co., Kansas**	86.7	6.0	0.9	6.4	980	.6170
West Chanute field, Wilson Co., Kansas**	94.3	4.2	0.7	0.3	1,025	.5683
Chickasha field, Grady Co., Oklahoma**	93.9	5.5	0.6	None	1,044	.5841
West Chanute field, Wilson Co., Kansas	86.5	9.0	0.3	4.2	1,031	.6166
West Chanute field, Wilson Co., Kansas	89.7	6.0	0.5	3.8	1,009	.6025
West Chanute field, Wilson Co., Kansas	93.3	4.7	0.6	1.4	1,021	.5870
West Chanute field, Wilson Co., Kansas	89.7	6.2	0.6	3.5	1,014	.6030

*Analysed at laboratories of Oklahoma Natural Gas Corporation, Tulsa, Oklahoma.
**Sand gas.

cubic feet. In the Chanute-Altoona district of Wilson County, a well is considered of average size if it makes 40,000 cubic feet, and the best wells have a volume of 300,000 feet. Exceptionally large producers have been reported in the Paola-Kansas City shale area, the gauge of some wells producing from shale alone being as much as 900,000 cubic feet. Such large wells blow down rapidly to average volume and may cease producing after a few days, a situation which suggests that the source of gas is a "pocket."

Very little can be learned concerning the rock pressure of shale wells, as it is impossible to shut in the average well without killing it. The only accurate tests known to the writers are of wells which make no water. One well had a shut-in pressure of 170 pounds at a depth of 540 feet; another, 95 pounds at a depth of 410 feet; and a third, 248 pounds at 830 feet.

The reasons for the difference in size of the producers are undetermined as yet, but they are probably related to these factors: (1) local

richness of the shale in "gas-making" material, (2) porosity of the shale, (3) amount of fracturing and jointing, and (4) structure. Although the volumes of the wells vary considerably between adjacent locations, areas as large as several square miles contain wells of the same general class. In the greater part of eastern Kansas no gas is found in the shales in the same stratigraphic position as those productive in the shale-gas fields. Operators and drillers long familiar with production of this type have stated that where the shale is darkest in color the largest wells may be expected. A few gas wells in eastern Kansas produce from seams of coal. Samples of the producing zone taken from some shale wells contain tiny cubes of bituminous coal. These facts strengthen the belief that the volume of the wells is controlled largely by the local organic content of the shale.

Although the gas-yielding formation is very fine-textured, its pores probably serve as a reservoir for some of the gas, just as do the pores of a sand. Variations in sedimentation would cause variations in the porosity, which in turn would be reflected by wells of different volume.

Fracturing and jointing may influence the size of the wells. The amount of fracturing may depend on the intensity of folding or the character of the shale. Where extraordinarily steep dips exist, the shale may have been broken, especially in places where comparatively abrupt changes in dip take place. However, the gentle inclinations of the strata in the gas areas discourage belief that local folding has caused much fracturing. The jointing can be attributed to the same forces that made the joints in the limestones, and is the result of slight regional torsional movements. Shale high in organic material, that which approaches the constituency of bituminous coal, is probably easily jointed. Thus, the organic content of the shale may be important in influencing the amount of fracturing or jointing as well as in determining the quantity of gas originally generated.

Structure may also influence the size of the producing wells. General observations indicate that shale wells in deep synclines may be expected to be small, though anticlinal folds do not necessarily furnish the largest wells. It has been noticed, however, that showings of gas in shales are more common in wildcat wells on anticlinal structures than in those not so located. The information secured to date does not indicate a definite relation between the size of the wells and structure.

The richness of the shale in organic material and the porosity, caused largely by jointing or fracturing, are believed to outweigh other factors. Subsequent research may alter this view.

DRILLING AND EQUIPMENT

The shale gas wells are drilled with portable drilling machines. An 8-inch hole is carried to a depth a few feet below the "Big lime" (Winterset, Bethany Falls, and Hertha limestones) where the 6¼-inch casing is set. This casing is pulled after the well is equipped and only the drive pipe is left. The remainder of the hole is drilled with 6-inch tools and is finished just below the lower black shale. It has been proved a good policy to complete the hole 2-4 feet in the light shale beneath the gas-bearing strata. Within 10 feet below the black shale is an irregularly-occurring sand which may hold gas, heavy oil, or salt water. If this sand is tapped at points where heavy oil is present, the recovery of shale gas is lessened, as the oil clogs the tubing and the well equipment. The salt water from the sand must be lifted with that from the shale, an added burden to the operation of the well. Of course, if gas is encountered, it increases the value of the well, but the uncertainty of finding gas deters most operators from testing the sand. Some wells which are high structurally are deepened to the Bartlesville sand, 230-250 feet below the top of the Cherokee shale. If the Bartlesville and the Cherokee sands above are missing or do not hold gas, the hole is plugged back to the shale zones. Abandoned wells or dry holes that were drilled before the shale-gas industry was developed have been reconditioned by cleaning out the plug to a depth below the Fort Scott limestone. Poor logs have handicapped many such endeavors, and shale wells secured thus are not generally as productive as new wells.

The wells are equipped for operation by running a string of 2-inch tubing. An anchor packer attached to the tubing is set in the "20-foot lime" of the Fort Scott. A pressure chamber is thus created in the lower part of the hole. Below the packer, in order, are a heavy collar containing a machined ring-seat, cage, perforated nipple, and anchor. A string of 1-inch pipe is placed inside the 2-inch. At the end of the 1-inch is a lead seat which bears against the machined ring set in the 2-inch string. The gas and salt water from the shale enter the 2-inch perforated nipple and the cage (Fig. 2), and pass up through the 1-inch tubing into a drip or separator at the mouth of the well. The drip is a section of 8-inch pipe with the ends sealed by welded caps. Before entering the lease-gathering system the gas goes through a line drip, additional equipment for eliminating the moisture. The field meter is also protected by a drip. After being measured, the gas enters the main gathering line to be transported to market. Most lease lines are 2 inches in diameter. They are buried

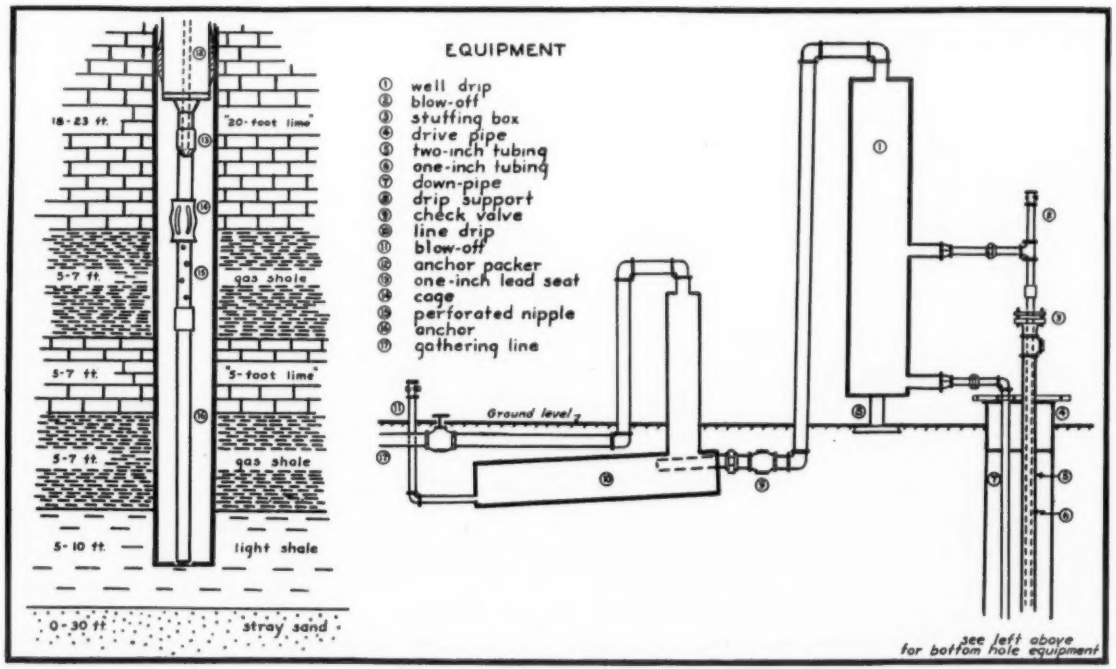

FIG. 2.—Equipment of a shale-gas well. The line drip is variable in design as influenced by the ideas of different operators. Thicknesses of formations are typical of the Chanute-Altoona district of Wilson County. The amount of salt water passing through the well drip in a day ranges from 5 to 10 barrels. The well drip is a section of 8-inch pipe about 8 feet long.

or left strung on the ground at the option of the operator. Most lines not larger than 5½ inches in diameter are constructed of welded flues originally used in boilers, or second-grade welded line pipe. All well connections except those that need to be broken frequently are welded.

Suspended in the drill hole outside the 2-inch tubing is a string of 1-inch "down-pipe" which conducts away the salt water brought up with the gas. The discharge end is beneath the head of water in the hole a distance sufficient to form a seal on the drip with pressure greater than the pressure of the field line into which the gas is delivered. The length of the down-pipe ranges from 150 to 250 feet, determined by the amount of pressure in the gathering system. Its twofold purpose is to carry away the salt water brought from the well and to seal the drip so the gas will be directed into the field line.

The cost of drilling and equipping an 800-foot shale well in the eastern Kansas district is itemized in Table II.

TABLE II

ITEMIZED COST OF AN 800-FOOT SHALE-GAS WELL

Drilling, including pipe rental, 800 feet at $1.10	$ 880.00
Tubing (2-inch), 800 feet at $.18½	148.00
Tubing (1-inch), 800 feet at $.09	72.00
Tubing (1-inch down-pipe), 250 feet at $.09	22.50
Packer with cage attached	40.00
Machined ring and lead seat	6.00
Perforated nipple 2 feet long	2.50
Stuffing box	2.50
Well drip	8.00
Fittings	5.00
Total cost	$1,186.50

Operators who have their own drilling machines may complete an 800-foot well with a total cash expenditure of approximately $900.00. Such operators own a large per cent of the eastern Kansas shale wells and are responsible for the present extent of the industry.

Spacing of wells.—By general practice one shale well is drilled in the center of a 40-acre tract (Fig. 3). Even this wide spacing may be considered too close. The land divisions, however, make it the most logical system of location. A shale well that is a "clean-out" of a dry hole may be 150-250 feet from property lines, but this close offset may be counteracted by a well an equal distance from the line, but on a part of the lease not offset by the competitor's well. In territory that does not yield large wells and is divided into blocks of leases controlled by a few operators, a shale well to each 80 acres is the most economical spacing.

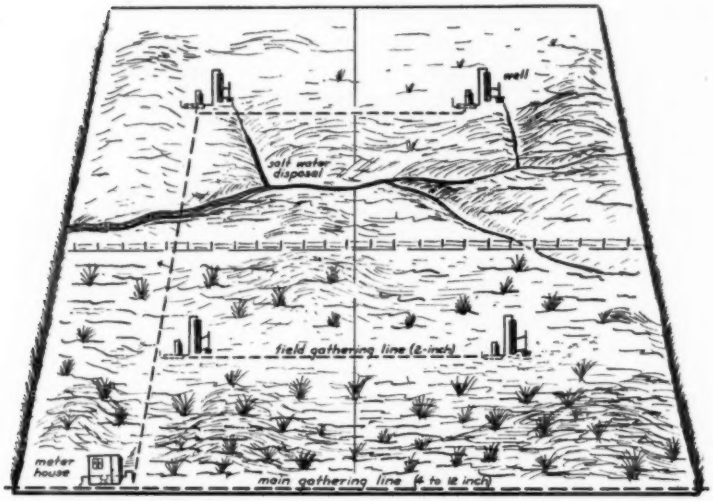

FIG. 3.—Sketch showing the development and equipment on a 160-acre tract on which a shale-gas well has been drilled in the center of each 40 acres.

OPERATION AND MAINTENANCE

The method of operating and maintaining the ordinary shale well is so different from that required for wells producing from sand that it has been thought best to describe the method in detail. In sand wells, salt water is ordinarily troublesome only after the pressure has declined considerably, and then the water encroachment is gradual, but nearly all shale wells make a large amount of water from the beginning and must be equipped to handle this water immediately after being tubed. A correct test of their open flow can not be taken until the well drip is in place. Sand and shale wells, however, have one feature in common—they can be operated profitably only so long as the water can be handled economically. As soon as swabbing is required too frequently, the well must be abandoned.

The most important factor in the handling of a shale well is the regulation of the line pressure against which the well is operating. Wells in some areas seem to work best against a pressure of a few pounds, and those in others against a pressure of as much as 50 pounds. This is caused by (1) the depth which controls the initial pressure of the well, and (2) the open flow. Pressure alone will not lift the water—there must be enough volume to elevate it into the drip. A large well may be capable

of lifting the water through 2-inch tubing, but some of the small wells will not lift it through 1-inch, and must be tubed with ¾-inch and possibly ½-inch pipe. The smaller the tubing the greater the lifting power of the gas passing through it, and for this reason even the large wells are equipped with 1-inch pipe upon completion, because eventually the volume and pressure will decline and this size will be necessary. Wells with an open flow of 50,000 cubic feet or more will ordinarily "clean themselves" when the 1-inch tubing has been run and the packer has set. They are then ready for the installation of the drip and line connections. Small wells, however, often require swabbing after being tubed, to remove the water which has accumulated in the bottom of the hole. It is ordinarily necessary to run the swab only once or twice to start the well. This swabbing can best be done while the drilling machine is still over the hole. If the well is put on the line immediately after the water has begun to come, it will not need additional attention for some time. However, if it is left to blow into the air, it may "go dead." A large shale well can generally be shut in without being damaged. The small wells, if shut in for only a few minutes, may become water-logged and require swabbing to start them. Accordingly, most operators never shut in their wells completely even when there is no market for the gas, but let them either blow open at full capacity or install pop-valves on the drips, which are set to open at whatever pressure is considered best for the well, ordinarily 15-50 pounds. If several months are to elapse before the completed well can be connected with a pipe line, it should be shut in entirely and then swabbed when connections are ready, because, if left to blow open for a month or more, it may lose so much of its volume and pressure that it will be permanently damaged and never come back to its original state.

The average shale well is rather sensitive to variation in the line pressure against which it works. A well may be in excellent condition, putting out 50 per cent or more of its open flow against a line pressure of 40 pounds. If the pressure drops to 20 pounds, it would naturally be supposed that an increased delivery would result. In some wells this happens, but in others the delivery decreases. If the line pressure rises again to 40 pounds the well may never put out as high a per cent of its open flow as formerly. A well should be operated at a pressure as nearly uniform as possible. The ideal working pressure is probably that at which the well will deliver 40-50 per cent of its open flow. Delivering this amount, the well keeps an almost constant stream of gas and water rising into the drip. If only a small part of the volume is delivered, only

a small amount of water is lifted, and the well may become water-logged. A well may also become water-logged from feeding against a very low pressure, which lowers the working pressure of the well to a point below that at which it can raise the water. Wells of 100,000 cubic feet volume require little attention, but those of only 20,000-30,000 cubic feet—and there are many of this size and smaller—may need to be swabbed frequently.

Swabbing is commonly done with a bailing rig mounted on a motor truck. The bailing rig consists of a small gasoline engine on the bed of the truck, a wire line and reel, a mast or tripod, and a 1-inch swab. Some operators use an automobile instead of a truck, and by means of a reel bolted to one of the rear wheels they utilize the automobile engine for power. Another method is to use compressed air to force the water out of the well. The ideal machine for reviving dead wells is a combination swabbing outfit and air compressor. The same engine that is used for swabbing operates a small air compressor also mounted on the truck. Where the air method works satisfactorily it is more desirable, as it is much quicker than swabbing. To blow a well, the stuffing box is loosened, the drip disconnected, and by means of the tripod and block and tackle the 1-inch pipe is raised a few inches off its seat. The air line is then connected to the 2-inch through the tee, which is a part of the well equipment, and the stuffing box again tightened. Compressed air is admitted and forces the accumulated water out through the 1-inch tubing. It may be necessary to start the well several times before it will continue to function unassisted. For some unknown reason the air method does not always work satisfactorily and swabbing must be resorted to. It is best for any producer who has many wells to have the combination machine.

Because of the construction of the automatic drips used on shale wells, an increase in the line pressure against which the well is equipped to work may cause the gas to escape from the lower end of the down-pipe. Under such a condition the down-pipe must be lengthened, thus submerging the lower end to a greater depth and sealing the drip against the higher pressure.

If the drill hole takes up all the salt water produced, there is no danger of the water doing damage to crops, but if the hole overflows, some provision must be made to carry the water away. A ditch is plowed to the nearest depression, or the water is directed into an earthen tank from which it can evaporate. If valuable farm land surrounds the well, it may be necessary to pipe the salt water a considerable distance to such a tank or where natural drainage will carry it off. The principal danger

of damage is in contamination of water wells. To avoid this, sufficient drive pipe should be set to case off the shallow water-bearing formations. Ordinarily two joints of 8-inch pipe are enough.

PRODUCTION AND DECLINE

Shale-gas wells have a wide variation in size and a corresponding variation in delivery of gas and revenue to the operator (Fig. 4). In addition to the dry holes, some shale wells never pay out; a few have returned the complete investment in six months. Each well has a different history, controlled by volume, marketing conditions, pressures, equipment, and experience of the producer in caring for it.

A shale well that comes in with a volume of 40,000 cubic feet would pay back its cost in approximately 3½ years if its average delivery was

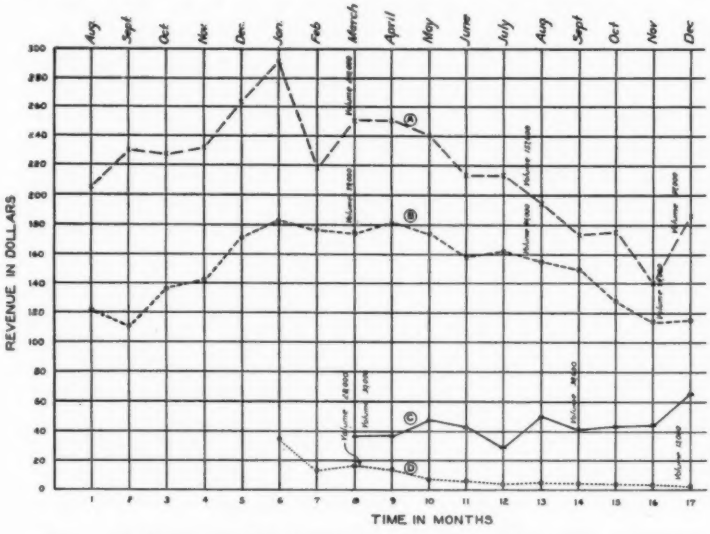

FIG. 4.—Decline curves of shale-gas wells showing variation in revenue to operator with net price of $.07 per 1,000 cubic feet. Curves *A* and *B* represent wells much larger than the average. They are in the same area and gave like response to operating conditions. The increase in delivery in the last month is due to the lowering of the line pressure. The natural decline of the wells is believed to have begun in March. These wells paid out in 6 months. Curve *C* is that of an average well which has a steady production due primarily to its isolated position half a mile from any other well. It delivers approximately 50 per cent of its open flow against 40 pounds line pressure. Curve *D* represents a shale well that delivers consistently but in too small amounts to be profitable. Open flow of the wells at different times is indicated. Date of curves is from August, 1927, to December, 1928.

15,000 cubic feet per day throughout this period. This delivery allows for the natural decline of the well and the average of summer and winter operations and market conditions. In this estimate, there is taken into consideration a net return of $.07 per 1,000 cubic feet to the operator, 6 per cent compounded interest on an investment of $1,200, and the value of the well equipment at the end of the period.

Partial records of three of the best wells of the Chanute field are here given.

1. A well which tested 99,000 cubic feet open flow on March 1, 1928, and 79,000 on November 3, 1928, delivered 27,097,000 cubic feet during the year against 50 pounds line pressure. The net return to the operator was $1,896.79.

2. A well which had an open flow of 210,000 cubic feet on March 1, 1928, and 97,000 on November 19, 1928, produced 36,622,000 cubic feet, an average of 100,000 per day, and gave a return during the year of $2,563.54.

3. A well from which 37,976,000 cubic feet was sold in 1928 tested 314,000 on February 10 and 114,000 on November 15. The amount received by the operator during the year was $2,658.32.

When consideration is given the possible reservoir space in 40 acres of the gas shale of average thickness, 12 feet, the question arises as to the source of all the gas produced by the largest wells. If the shale has a reservoir space of 10 per cent and the gas is confined under 250 pounds pressure, the equivalent of approximately 32,000,000 cubic feet would be present, calculated at 2 pounds above atmospheric pressure. The shales contain large quantities of salt water which would tend to lower their capacity for gas. The largest wells produce as much as 35,000,000 cubic feet of gas the first year, and at the end of the year they may be delivering at the rate of 20,000,000 cubic feet per year and may produce 200,000,000 cubic feet in their active existence. The conclusion is forced, therefore, that gas is drained from an area much larger than 40 acres, or it feeds in from other formations. If drainage takes place beyond the limits of the 40 acres, fracturing and jointing may be more important than is generally recognized. Fracturing might be confined to zones of considerable length but sufficiently narrow to pass between wells of small volumes, thus explaining the presence of such in the vicinity of a large well supposedly tapping the fracture zone. An interlocking joint system might be feeding a well from a great area.

Some exceptional shale wells may have been drilled unknowingly into the stray sand a few feet below the black shale. Inasmuch as this

sand locally contains gas, an additional amount of gas may be credited to the shale. It is certain, however, that most of the very large wells produce from shale alone.

The chief asset of the shale wells is their slow decline in volume. No trustworthy estimate of the life of the wells can be made with the history of the industry so short. A few wells have been abandoned after a year or two, but most of them, ranging in age from 2 to 7 years, are still in operation. The small wells—those varying from 20,000 to 40,000 cubic feet—do not show much decline. Larger wells, testing from 100,000 to 300,000 feet when drilled in, may lose ⅔ of their open flow before the end of a year. The subsequent decline is much more gradual. The production of the shale wells is subject to a natural decline similar to that of sand wells. The slow rate of decline can be attributed to the nature of the reservoir rock and the small tubing with which the wells are equipped. A sand-gas well would show a very gradual loss in volume if produced through 1-inch tubing.

The shale wells may be operated for 25 or 30 years. The economic life of such wells will be terminated when the cost of increased attention, due to small volume and low pressure and the cost of keeping the equipment in good condition, exceeds the revenue from the well.

MARKETS AND PRICE

The gas industry of eastern Kansas is favored with good markets which include cities, cement plants, brick plants, smelters, condenseries, ice plants, and railroad shops. The cement plants are the largest consumers, some using 10,000,000 cubic feet daily.

Since shale-gas wells are so sensitive to changes in line pressures, the producer should consider the type of market which the gas purchaser supplies, before signing a purchase contract. The ideal market is one which demands practically the same amount of gas day after day and 24 hours of the day. Such markets are the cement plants, brick plants, and smelters, which are in constant operation. City distributing plants alone are very unsatisfactory, as they use a large amount of gas during their peak loads in the day time and a comparatively small amount during the night, and the result is a wide range in line pressure in the gas fields.

The price of the gas is $.08 to $.10 per 1,000 cubic feet at the well. If the well owner lays a line to the main line of the purchaser, he is paid $.02 to $.04 more per 1,000. Field measurements are made on a 2-pound pressure basis.

GEOLOGICAL NOTES

AGE OF THE GUAYAQUIL LIMESTONE

The Guayaquil limestone has been referred to by many authorities as Cretaceous, this presumably by reason of the fact that it was first described as such by Wolf, in his *Geologia y Geografica del Ecuador*, published in 1892.

Wolf's principal evidence for the Cretaceous age of this formation was based upon the identification of certain fossils by Geinitz, of Berlin, who recognized *Inoceramus* and other typical Cretaceous forms which were alleged to have been actually collected from the limestone in Guayaquil. It has been impossible to trace these fossils in any collection or museum in the country, however, and as no forms similar to those described by Geinitz have been found since in the limestone, it has been assumed by the present writer that the fossils were collected probably from some other source, for example, from the interior east of the Andes, where Cretaceous rocks are known to occur. It is possible that Wolf, therefore, had forwarded wrongly labelled specimens to Geinitz for identification.

The lithological similarity between Cretaceous limestones and the Guayaquil deposit has also led more recent observers to describe the latter formation as Cretaceous in age, in spite of the absence of positive paleontological evidence.

In order to have an authoritative expression of opinion upon this question, the writer dispatched both a specimen of the rock and a microscope slide of the same material to T. Wayland Vaughan, of the University of California, who was kind enough to send the following communication.

> ....The principal organism on the slide is a small lenticular species of *Discocyclina*. There are several vertical sections and there are also sections which show the equatorial chambers.... the species is very close to *Discocyclina cubensis* (Cushman). We have been referring the deposits in Cuba in which *D. cubensis* occurs to the Upper Eocene, but I am not altogether sure that the horizon is quite so high. However, your rock is certainly Eocene. The chances are that it belongs to the upper part of that series. If the beds from which your specimens came were ever referred to the Cretaceous the determination of the stratigraphic horizon was erroneous.[1]

[1]Personal communication from T. Wayland Vaughan.

Vaughan's observations need no further comment.

It has been determined by the present writer that no Cretaceous rocks of any kind have been recorded from the province of Manabi and, with the assistance of Vaughan's investigations, it may be suggested that no Cretacous formations occur west of the Andes in southwest Ecuador. The extensive ranges of hills known as the Cordilleras de Chongon and the Cordilleras de Colonche (indicated on Wolf's map as Cretaceous) must, therefore, in the light of present knowledge, be regarded as wholly Tertiary.

GEORGE SHEPPARD

STATE GEOLOGIST, REPUBLIC OF ECUADOR
CASILLA 410, GUAYAQUIL, ECUADOR
February 2, 1929

GALENA AND SPHALERITE IN THE FAYETTE AT ORCHARD SALT DOME, FORT BEND COUNTY, TEXAS[1]

Galena (*PbS*) and sphalerite (*ZnS*) have been found at several of the salt domes of the Coastal Plain of Texas and Louisiana, but seldom have these occurrences been found outside the dome proper. For this reason, and the bearing it may have on the origin of the galena and sphalerite, the extradomal occurrence in the Fayette[2] here mentioned may be of sufficient interest to be worth recording.

The galena and sphalerite discussed in this note were found in the samples from the Gulf Production Company's John M. Moore No. 7, located on the east side of the Orchard dome, Fort Bend County, Texas.

Although the Orchard dome is in the northwestern part of Fort Bend County, it is within the area of marine Oligocene. The base of the

[1]With permission of the Gulf Production Company.

[2]The age assigned in the literature to the Fayette has ranged from Lower Claiborne (Eocene) to Miocene. However, the work, particularly of Deussen and Matson (Alexander Deussen, *U. S. Geol. Survey Prof. Paper 126*, 1924, pp. 80-91), and Berry (Edward Wilber Berry, *U. S. Geol. Survey Prof. Paper 92*, 1924, p. 5), as well as the later work by Bailey (Thomas L. Bailey, *Univ. Texas Bull. 2645*, 1926), seems sufficient definitely to allocate the Fayette, or, to quote Deussen (pp. 80-81), "....the Fayette sandstone lies....above the Jackson formation....overlain by the Catahoula." Bailey's name Gueydan is approximately equivalent to Deussen's Catahoula (Bailey, pp. 15-16). Miss Alva C. Ellisor has stated to the writer that she has verified this position of the Fayette on the surface, and the work of the writer has verified it in the subsurface.. It is in the sense of Upper Jackson that the term Fayette is used in this note.

Roy Hazzard has told the writer of examining ash beds at this same position in the section (below the Vicksburg and above the Jackson) near Rosefield, northeast of Jena, La Salle Parish, Louisiana. W. C. Spooner informed Mr. Hazzard of the outcrops. It seems very likely that these ash beds represent the eastward continuation of the Fayette across Louisiana.

Oligocene in Moore No. 7 is near 3,900 feet. The samples containing the galena and sphalerite are from depths between 4,000 and 4,550 feet, or in the upper part of the Fayette. The beds between these depths consist of clays, clayey silts, and clayey and silty sands. Few of the sands are free from clay and silt. In color they are for the most part green and gray of various shades. Some are darkened, even nearly to black, by carbonaceous material. Scattered through these are numerous beds composed almost entirely of volcanic ash. Most of the ash flakes are much devitrified, but retain their original texture remarkably well. The log of the well shows no single bed or type of material being penetrated for more than 25 feet; the thickness of most beds is much less. These beds are considered to be of estuarine and continental, rather than strictly marine, origin.

It is in this section, particularly in the ash beds, that the galena and sphalerite occur, although neither occurs in large amounts. The galena is found in anhedral crystals of different shapes. A few are nearly cubical. The largest crystal noticed is approximately 3 millimeters in length. Ordinarily they are very much smaller. The sphalerite is light yellow and occurs in small anhedral grains. Few sphalerite crystals are more than one millimeter in length. Both the galena and sphalerite are secondary. Many ash flakes are partly or completely enclosed in galena.

Galena was noticed in the Fayette samples from the Gulf Production Company's John M. Moore No. 7, also at the Orchard dome. A few other such occurrences have been noticed in the Fayette on other coastal domes of Texas. Galena has been noticed in one place in an Oligocene gouge zone sheared in anhydrite at the High Island dome, Galveston County, Texas.

The origin of the galena and sphalerite is, of course, not known, since both are secondary; however, the several extradomal occurrences in the Fayette are suggestive, and it seems likely that this formation is the source of at least a part of the galena and sphalerite which occur on and near the coastal salt domes.

MARCUS A. HANNA

HOUSTON, TEXAS
February 26, 1929

DISCUSSION

COURSES OF DRILL HOLES

I have read the interesting and instructive paper by Martin Van Couvering in the February (1929) *Bulletin* with regard to the deviation of oil wells from the vertical and methods of surveying them, and it might be a help to some of the *Bulletin* readers to mention another instrument for surveying drill holes, the Maas drill-hole compass, upon which the diamond-drilling industry has been relying for several years and which I have used successfully.

The advantage of this method of surveying wells is that the apparatus can be lowered into the well quickly, attached to any tools which are ordinarily lowered into the well on a rope, thus avoiding the slow and laborious screwing and unscrewing of drill pipe and any possible inaccuracy which may arise in measuring the rotation of the drill pipe as each stand passes into the hole. By this method the angular deviation from the vertical and the compass direction of the deviation may be determined at the same time and the permanent record of both secured. Brass rods are used between the compass and the drilling tools.

Aside from the effect on the productivity of the well caused by its deflection from its intended location, it is of course obvious that subsurface structure calculated upon the basis of deep-well records is well-nigh valueless unless the exact point where the well penetrates the key-bed is determined by surveying the well, as was pointed out by Mr. Van Couvering in his excellent paper. I have surveyed one drill hole which, although started vertically, had attained a deflection of 64° from the vertical at a depth of 2,300 feet and at that depth was more than ¼ mile away from the surface location, measured in a horizontal plane, and have surveyed several other drill holes with only slightly less deflection from the vertical. In the course of surveying hundreds of drill holes it was found that practically all deviated enough from the vertical to make a survey advisable.

Mr. Van Couvering states that his investigation did not reveal the existence of any agency which would result in a deflection in a pre-determined direction. With regard to this, I wish to say that I have successfully deflected drill holes in a pre-determined direction by placing a pilot wedge in the hole, surveying with the Maas compass the direction of the pilot wedge, and then placing the main wedge of steel in the hole, attached to a guide wedge at such an angle that when the guide wedge engaged the pilot wedge already in the hole the main wedge had its beveled surface pointing so as to deflect the hole in the desired direction. I have no doubt that this method could be adapted to oil wells with a little experimenting, and the cost of making the wedges would be a small matter compared with the total cost of a well.

E. E. WHITE

PAINTSVILLE, KENTUCKY
February 21, 1929

GRAPHICAL METHODS OF CALCULATION IN INTERPRETATION IN WORK WITH THE TORSION BALANCE

A DISCUSSION OF C. A. HEILAND'S "A NEW GRAPHICAL METHOD FOR TORSION BALANCE-TOPOGRAPHIC CORRECTIONS AND INTERPRETATIONS," THIS *Bulletin*, VOL. 13, NO. 1 (JANUARY, 1929)

In his review of the several types of graphical methods, Heiland writes:

> Vertical graticules are very suitable for the evaluation of vertical cross sections of subsurface structures at right angles to their strike, provided that their extent in the strike, on either side of the section, is virtually infinite. The first to make use of B. Numeror's suggestion was D. C. Barton, who published diagrams for such infinite structures. He attempted also to modify this method for structures which are finite in the strike. This, however, leads to difficulties, as for any one structure (a dome, for example) the ratio of thickness to the length of the mass elements changes as the depth. The diagrams obtainable for such finite lengths of the elements in the strike permit only an approximate determination of their effects, because it is impossible to construct diagrams for all the possible ratios of thickness to length.

The first crude predecessor of the writer's present horizontal prism type —constructed in 1924, approximately one year before the publication of Numeror's vague suggestion of the possibility of this type of graphical calculation —was designed particularly with salt domes in mind. The present type of the charts was evolved in a very careful and detailed calculation of the amount of cap rock of the Bryan Heights, and one of the writer's standard series of charts is specially designed for use in very accurate calculations in regard to salt domes. Of the 7 charts published by the writer in the paper referred to by Heiland, only 2 were for the infinite case and the other 5 charts were for finite structures. The graph of Figure 1 of Heiland's paper, after Figure 14 of the writer's discussion in *A. I. M. E. Tech. Pub. 130* (1928), is constructed with constituent prisms with a finite ratio of length to depth (ratio ½ length to depth 2:1 or 3:1, the writer does not remember which) and not with an infinite ratio. The writer finds no difficulty in the practical application of this type of graphical calculation to finite structures with axes of symmetry.

The difficulty envisaged by Heiland practically does not exist. The probable error in field observations is as large as, or larger than, the errors produced by considerable errors in the assumption of the length of the constituent prisms of the charts. A standard series of a few charts covers almost all ratios. The range of the absolute, and the relative degree of error in fair-to-good field observations of the gradient and differential curvature are shown in Table I. The values are based on the writer's general experience. In some areas, as, for example, where the Wilcox is at the surface, or in the Louisiana swamps, the errors run slightly higher.

The percentage of error produced in the gradient or differential curvature by an error in the assumption in regard to the length of a prism is shown by Table II.

In the calculation of gradient, therefore, an error of 20 per cent in the assumptions of length at right angles to the plane of the section is negligible if the half length is more than twice the depth; and an error of 10 per cent in the length is negligible if the half length is more than the depth.

TABLE I

ERRORS IN FAIR-TO-GOOD FIELD OBSERVATIONS

	GRADIENT			DIFFERENTIAL CURVATURE		
	Usual Size	*Absolute Error*	*Percentage of Error*	*Usual Size*	*Absolute Error*	*Percentage of Error*
Rarely as small as.....		1 E	4		3	7½
Usually.....	<25 E	2 E	>8	<40 E	6	>15
Occasionally as large as...		5 E	20		10	25

In the calculation of the differential curvature, an error of 10 per cent in the assumptions in regard to the length at right angles to the plane of the section is negligible if the half length is twice the depth, and for all lengths, if the prism is extremely wide. If the width is approximately of the same order as the depth, the error in the length assumptions must be less than 7 per cent, if the error in the calculated effect is to be negligible.

The impossibility of construction of diagrams for all possible ratios of depth to length, therefore, disappears. A suite of a few standard charts with

TABLE II

PERCENTAGE OF ERROR IN CALCULATED GRADIENT OR DIFFERENTIAL PRODUCED BY ERROR IN LENGTH OF PRISM AT RIGHT ANGLES TO PLANE OF SECTION

	GRADIENT						DIFFERENTIAL CURVATURE		
Percentage of Error in Length of Prism	±10	±20	±10	±20	±10	±20	±10	±10	±20
Z_1 *to* Z_2 *(Thickness of Prism)*	0.9 to 1.0	0.9 to 1.0	0.9 to 1.0	0.9 to 1.0	0.9 to 1.0	0.9 to 1.0	0.9 to 1.0	0.9 to 1.0	0.9 to 1.0
X_1 *to* X_2 *(Width of Prism)*	0 to ∞	0 to ∞	0 to 0.3	0 to 0.3	0.5 to 0.6	0.5 to 0.6	0 to ∞	0 to 0.7	0 to 0.7
V (Length of Prism)	*Percentage of Error in the Calculated Effect*								
±0.5	7.7	15.8	6.8	13.6	9.2	15.0		22.0	47.0
±1	4.5	8.9	2.7	5.7	3.7	7.4	1.1	15.5	30.0
±1.5	2.9	6.1	1.0	2.3	1.2	2.9		8.6	17.4
±2	1.9	4.0	0.7	1.8	0.9	1.7	6.5	5.0	10.5
±3	1.0	2.0	0.2	0.3	0.2	0.5	8.2	3.3	6.1
±4	0.5	1.1	0.04	0.1	0.05	0.2	8.9	1.8	3.6
±5	0.3	0.7	0	0	0	0.1	9.5	1.0	2.3
±6							9.3		

selected depth-to-length ratios will cover nearly all situations in which the gradient is to be calculated, and nearly all theoretical and many practical situations in which the differential curvature is to be calculated. For certain situations it will be necessary to form special charts. One of the writer's standard charts is for the situation in which the length is constant without regard to depth. Within the limiting depth-to-length ratios of such a chart, a pattern is obtainable for all depth-to-length ratios and it is a matter of simple drafting to expand it into a complete chart. If the depth-to-length ratio varies with depth, it is a matter of simple drafting, mainly of tracing and interpolation, to assemble the new chart from parts of the standard charts.

Great flexibility in handling variation of the length-to-depth ratio with depth may be obtained by constructing a series of standard charts, each with a constant length-to-depth ratio, by mounting the charts on light cardboard, and then cutting them into strips along the lines between the horizontal zones. A new chart can be quickly constructed for any variation of those standard length-to-depth ratios with depth, by assembling the correct strips from the various standard charts.

An alternative method may be used with the strips. Two sets of strips are used for each zone, one set drawn in black and regarded as positive and the other drawn in red and regarded as negative. The zero points of the strips of positive effect are arranged to delineate in a step-like fashion the left hand, and the strips with the negative effect the right hand side of the structure. The algebraic sum of the reading of the strips along any vertical line gives the effect at the intersection of that line with the surface. This method is easy and rapid for the calculation of the effects produced by a known body, but for calculating an unknown body from known effects, the method is not nearly so easy or rapid as the writer's charts and in the writer's work has been superseded entirely by the graphic charts.

An axis of symmetry is present in a large number of the structures in which the geologist is interested, and on account of the error which is permissible in the length-to-depth ratio, a larger number of structures may be assumed to have an axis of symmetry. Many theoretical problems of the torsion-balance interpreter may be investigated by calculations of effects along axes of symmetry. In view of the tediousness of calculations, particularly of calculations for points not on an axis of symmetry, most of the needs of the geologists and geophysicists will be fairly well satisfied by a cross section of the structure and the gravity anomaly along an axis of symmetry.

In the calculations along an axis of symmetry, the sole advantage of the various methods making use of spherical or cylindrical coördinates is that one chart or a set of two charts is applicable without regard to the length-to-depth ratio. The extremely great disadvantage is in the very great number of cross sections which must be handled. In calculations of a cross section of anticlines or domes, a minimum of seven stations must be used. If octants (or, better, 22½-degree sectors) are used in the calculations for those seven stations, a total of 22 (or 50) different cross sections must be handled. If the effects are being calculated for a known body, the drafting of the 22 (or much more, 50) cross sections itself will be a time-consuming task; and if the probable form of an unknown body is being calculated from an observed gravity anomaly, the

simultaneous handling of 22 (or much more, 50) different sections in the molding and remolding of the structure is difficult to the point of impracticability. The time required to count the quadrilaterals will take about 4 (or 8) times as long as with the writer's method, as there are 4 (or 8) times as many sections to a station and as the sections are of approximately the same character under the two methods. If octants are used, the question of approximation of the assumed to the actual form of the anomalous mass arises, but if 22½-degree sectors are used as recommended, the necessity for constructing and handling 8 cross sections for each station makes the method entirely impractical in commercial work on account of its tediousness.

The results obtained by the use of charts such as suggested by the writer are approximate and, in general, not as accurate as those which are obtained by the use of Heiland's method or the other similar methods, but as the degree of error in them in general is considerably less than the probable error of the results with which they are to be compared, the slightly higher accuracy of the latter is without significance. Considerable time is required to construct the standard series of charts and if only a small amount of calculating is to be done, it may be preferable to use structure contours and one of the methods based on cylindrical coördinates or a very neat method devised some years ago by Lancaster Jones, who is only now publishing it. But if much calculation is to be done, time will be saved by construction of charts of the type suggested by the writer. Such charts, however, are entirely unadapted for calculations for points not on axes of symmetry or for any points on unsymmetrical structures. For calculations in regard to such situations, the writer uses a method based on structure contours and cylindrical coördinates.

In calculations with points not on axes of symmetry, in general, the use of the spherical coördinates in Heiland's method places it at a disadvantage compared with the similar methods based on the use of cylindrical coördinates. The construction of the cross sections is rather tedious. If a method based on cylindrical coördinates is used, a template can be superimposed on a structure contour map, if necessary with two or three sets of structure contours in different colors. The respective elevations for each little sectoral zone of the template are then read off and looked up on the graph, or in an equivalent table. If the graph is based on spherical coördinates, this is not possible unless the relief of the anomaly lies within 25° from the horizontal plane through the station. Graphs or tables based on the use of cylindrical coördinates can be calculated with the same mathematical rigor as for spherical coördinates. For the calculation of the terrane correction, Heiland's method is at no disadvantage on account of its use of spherical coördinates, but has no advantage over the methods using cylindrical coördinates.

DONALD C. BARTON

HOUSTON, TEXAS
March 14, 1929

I may be permitted to reply in a few words to the comments made by Dr. Barton on my graphical method published in the January, 1929, issue of this *Bulletin*.

Dr. Barton compares my method with his graphical method which is applicable in interpretation work only and primarily for structures with an axis of symmetry. The method suggested by the writer, however, is not only applicable to the computation of the effect of structures on stations in their axis of symmetry, but also on stations in any location above irregular bodies; furthermore, it is applicable to the computation of terrain corrections, an advantage not possessed by Dr. Barton's method. A method of an applicability so universal as that suggested by the writer may of course involve certain disadvantages if applied to certain problems of interpretation for which special methods have been devised. In order to make a method applicable to both terrain correction and interpretation, the principle of cross sections through the disturbing masses at each station must be applied.

However, the work involved in the evaluation of these cross sections is not nearly as great as Dr. Barton calculates from a theoretical investigation of the method. His statement that considerable time is required to construct the standard series of charts is in conflict with the facts, inasmuch as, contrary to his method, there are no offsets in the radial boundaries of the elements. These boundaries need be determined only once for one diagram in the writer's method, while they change in Dr. Barton's method for every horizontal layer; if there are 10 to 20 layers, the time involved in the construction of such diagrams is at least 10 to 20 times as much as that involved in the writer's method. The mere fact that for the determination of 4 gravity derivatives in 16 azimuths only 6 diagrams are required is sufficient proof of the simplicity of the method. The writer has given complete directions for the construction of such diagrams so that they may be adapted to any conditions, whereas Dr. Barton has not published such details as yet on his method, so that a comparative investigation concerning the time necessary for the construction of diagrams for either method, and concerning the practicability of the two methods under varying conditions by an uninterested person is very much handicapped.

The method of using cross sections in various azimuths through the structure is not merely of academic value but has proved valuable in commercial work. At the 14th annual meeting of the Association at Fort Worth, the writer received favorable comments by geophysicists of oil companies on the simplicity of the method and its applicability to practical situations of diverse nature. Besides, the writer is not the only one using azimuthal sections for three-dimensional structures; the method published by H. Haalck, geophysicist for the "Exploration," which is the oldest company doing commercial torsion-balance work, involves the same principle.

In comparing the time required in using his or the writer's method, Dr. Barton comes to conclusions which seem rather unfavorable for the writer's method. However, the two methods are not equivalent relative to the counting of the elements, as there are no offsets in the writer's diagrams; therefore, the effects of large parts of the structure under investigation may readily be calculated by multiplying radial and angular number of elements on the outline. In addition, it is impractical to use three-dimensional diagrams throughout the whole process of interpretation; at the beginning, the field data are reduced to a two-dimensional case and calculations are made for at least two perpendicular sections. If the structureal sections have irregular outlines, the use of

Amsler's planimeter with modifictaions recently suggested by Gamburzeff may expedite the work. At the very end of the interpretation process, three-dimensional diagrams should be applied; the amount of calculation involved is not excessive as compared with the greater reliability of the data, inasmuch as the major portion of the structure determined by two-dimensional methods is constant and only relatively few elements are added or subtracted in molding and re-molding the structure in many, but not all, azimuths.

I agree with Dr. Barton that his method is easier to handle for stations on an axis of structural symmetry. For stations asymmetrically located on irregular bodies, Dr. Barton uses the contour method together with cylindrical coördinates. It must be borne in mind, however, that the application of this method is limited to structures with gentle dip, as the integrations of the vertical mass-column always involve approximations in order to make the computations at all practicable. For asymmetrical irregular structures of steep dip or for irregular ore bodies, the only methods that remain applicable, if reliable results are desired, are those suggested by H. Haalck and the writer.

The progress made recently in methods for torsion-balance interpretations and terrain corrections are indeed remarkable. The most recent improvement which has been reported is an integraph designed by Professor Schweydar for the almost automatic determination of the gravity data for terrain corrections and interpretations. Details have not as yet been published, but it is hoped that the instrument will soon be available.

C. A. HEILAND

GOLDEN, COLORADO
March 26, 1929

REVIEWS AND NEW PUBLICATIONS

Petroleum and Coal—the Keys to the Future. By W. T. THOM, JR., *Princeton University Press* (Princeton, New Jersey, 1929). 223 pp., including bibliography; 40 figs.

The book by Dr. Thom is the outgrowth of a series of lectures presented to undergraduates at Princeton University. Of its 12 chapters, 4 are devoted to coal and 4 to oil, giving the origin, classification, geologic and geographic distribution, and methods of exploration, exploitation, and utilization of both substances. Inasmuch as the entire book contains only a few more than 200 pages, of which approximately 40 are given to illustrations, the treatment is necessarily brief. For the purpose in hand, however, the material seems to the reviewer to be well chosen. Chapters 4 and 9, on the coal and oil fields of the world, respectively, give excellent summaries of the world's known supplies of the mineral fuels within very small compass.

To those already acquainted with the coal and petroleum industries the principal interest centers in chapters 1, 6, 11, and 12.

Chapter 1, entitled "Ancient history as an index to future influence of petroleum and coal upon national development and international relations," reviews the fundamental importance of the quest for the metals in the history of mankind and the even greater necessity of the metals in modern civilization. Coal and petroleum are the means by which the metals can be recovered and utilized, and modern civilization is dependent upon them as ancient civilization was upon the easily-worked metallic deposits and upon the man power to work them. "Man's ability to control the stored energy of coal and oil is, therefore, at once the distinguishing characteristic, and the basis, of modern civilization, and the events of recent history are reflections either of improvement in the methods of using mineral fuels, or of nationalistic intrigues and struggles involving the control of one or both of these mainsprings of industry and keys to economic and military power."

Chapter 6, "The status of the coal industry," deals with the present rather serious condition of that industry both in the United States and in other countries. Chapter 11 treats of the social importance of coal and oil and their present competitive status, and Chapter 12 deals with the reserves of coal and oil and their effect on the future of civilization. The author's conclusions are shown by the following quotation: "Our coal reserves appear to be large enough to last, with due economy of use, for a thousand years or more—that is to say, far beyond the range of valid prediction. The world's reserves of oil practically available by methods now in use, although of scant size when viewed from a broad national or humanistic standpoint, appear to be so capable of multiplication (in so far as practical effect is concerned) by economics of use, by improvements in methods of discovery and production, and by the use of supplementary sources of energy, that the situation is one calling for sound judgment and careful planning for the future, rather than for pessimism and alarm..... Petrol-

eum and coal, as keys in the hands of statesmanship and science, can unlock the future, but what that future will be will depend upon the collective intelligence and conscience of civilized man. . . . . With international coöperation in a reasonable and friendly spirit the problems of humanity can be solved. If international competition and discord prevail, our civilization becomes like a kingdom divided against itself and will be brought to desolation."

The quotations give the dominant thought of the book, which is carried through all the chapters as well as those specially cited. The attempt to discuss the vital significance of the mineral fuels in so small a compass is successful, in the opinion of the reviewer at least, although in places a fuller treatment might be wished.

L. C. SNIDER

NEW YORK, N. Y.
February 25, 1929

"Petroleum in Persia." By C. P. NICOLESCO. *La Revue Pétrolifère*, Nos. 277-88 (Paris, 1928). 80 pp., 41 figs. and secs., and 4 maps.

This excellent work by Dr. Nicolesco covers in considerable detail all phases of the petroleum industry in Persia, beginning with the history of the fields and ending with the modern development of them by the Anglo-Persian Oil Company. The more notable subjects include: British petroleum policy; concessions and companies in Persia; petroleum indications; tectonics; historical geology; stratigraphy; petrography; paleontology; origin and migration of petroleum prospecting; comparison of Persian oil fields with others; production of oil; transportation of oil from fields; refining and cracking of Persian crude; and a summary and a very complete bibliography of the subject. As the brevity of this review allows only a partial summary, only general conditions of Persia will be discussed, as well as the main producing horizon, the Asmari. A geologic columnar section is reproduced, showing in abbreviated form the petrography, paleontology, origin, and tectonics of the formations related to the Asmari limestone.

Persia may be divided into five distinct provinces. (1) The Northern Mountains, extending from the Russian-Persian boundary to the Russian-Afganistan line, passing south of the Caspian Sea and north of Teheran, including the Taliche, Elbourz, and Ala Dagh ridges, which form a continuous chain. Petroleum indications in this area are definite, but seepages are few and widely separated. Much granite and gneiss are exposed, and the basaltic lava flows are very common. The Jurassic represents the main mass of the mountains, with the Cretaceous and the Miocene developed on the sides of the ridges. No petroleum production on a commercial scale has been developed in this area. Formerly covered by a Russian concession, this area is now controlled by the Persian Government, which plans to develop it. Several attempts of American companies to obtain concessions were unsuccessful.

(2) The Northern depression (Dacht-i-Khevir and Dacht-i-Lout), (3) the Central Mountains (Kerges, Chirkouh, Anarek, and Bafk ridges), and (4) the Southern depression, cover the whole of central Persia. The mountains show little granite and gneiss, very few lava flows, and very slight development

of the Jurassic; the Cretaceous, Miocene, and Pliocene are well developed. The Central Mountains do not possess any petroleum surface indications at all comparable with either the North or the South Mountains, but the presence of rich oil reserves there is scarcely doubted. The Northern and Southern depressions are covered by the Pleistocene and at this time are sand deserts.

(5) The Southern Mountains extend for a length of more than 1,100 miles, beginning at Mossoul and ending at Bender Abbas in the Hormouz Straits. The trend of the mountains is northwest-southeast, and the average width of the mountain area is approximately 150 miles. Igneous rocks are almost entirely covered, except at the northern end; the Jurassic, Cretaceous, Eocene, Oligocene, Miocene, and Pliocene beds are very well developed, dipping gently southwest. Indications of petroleum in all forms are plentifully present throughout the length of the mountains on their southwest slopes. In view of the development which has already taken place, the possibilities of Persia are almost unlimited. Three chief areas are most promising, the Mossoul on the north, the Chouchter in the central part, and the Bender Abbas on the south. Commercial production has been developed for several years in the Maidan-i-Naphtun of the Chouchter area, and recently in the much-disputed Mossoul area.

Oil is produced entirely from the Asmari limestone and from the overlying Far formation. The Asmari limestone is very hard and pure in its primary state, but its upper part is highly dolomitic, friable, and cavernous; locally gypsum replaces the limestone, either as beds or in irregular masses, with a few primary limestone inclusions. Overlying the Asmari is the Far formation, which produces in its lower zone, composed of secondary material derived, at least in part, from the Asmari. The lower Far is highly complex, containing salt, gypsum, anhydrite, marls, and limestone. The Asmari limestone is Oligocene in age, but evidently the dolomitization of its upper part and the deposition of the lower Far occurred in the lower Miocene. As indicated on the accompanying columnar section, the Asmari is well represented by *Foraminifera*. At the close of the Oligocene the Southern Mountains were in a geosyncline, with land masses exposed above water, thus causing the weathering of the Asmari. The following period of shallow marine and laguno-marine life was probably the source of the present petroleum deposits.

The commercial development has been discussed in many publications and does not require much comment. The production of several wells has been phenomenal, both in the initial production and in the total output, partly, of course, due to the large drainage area of individual wells. Well No. F7, for example, produced approximately 47,000,000 barrels in the 15 years of its life. The most important consideration is that regardless of how small the production per acre may finally prove to be, the total potential area is so large that it alone could easily supply the world's requirements for several years. The ownership of the whole concession by the Anglo-Persian Oil Company is, however, a guarantee that the fields will be developed slowly, and only as the market conditions will warrant.

BASIL B. ZAVOICO

CONSULTING GEOLOGIST
TULSA, OKLAHOMA
February 26, 1929

TABLE I (PETROLEUM IN PERSIA)

Formation		*Age*		*Character of Sediments*
Quaternary		Pleistocene		Shelly conglomerate, coastal coral reefs; delta and river alluvium; gravel; oölites with *Foraminifera* (*Miliolidae*); detritus
Baktiari	Upper	Pliocene	Upper	Massive conglomerate, gravel, limy material, cement
	Lower		Lower	Sand, gray limestone; red marl, clay; few conglomeratic beds in upper section
			Upper (Pontian)	
Far	Upper	Miocene	Middle (Helvetian)	Gray massive uniform limestone, alternating with clay and marl, in places red
				Gray limestone at top; clay and marl, some gypsum. Sandy limestones at base, with gypsum at their top
	Middle			Interbedded gypsum and clay; marl, blue and red, with calcitic concretions; at base, salt zone of salt, marl, gypsum, and a little anhydrite
	Lower		Lower (Burdigalian)	
Asmari		Oligocene		Limestone, massive and bedded, brown or gray-brown, gypsum in upper part, hard beds and shale at base; Asmari generally compact, hard, but in upper part cavernous, soft, dolomitic
Spatangides		Eocene	Upper	Marl, shale, gray-blue; fine shaly limestone at base
Upper, fine-bedded			Middle	Hard thin limestone, light green to dark brown, shaly in upper part; limestone, gravel, conglomerate, and shale at base
Blue and purple			Lower	Shale, light blue and red; thin limestone in upper part
			Danien	
Lower, fine-bedded		Cretaceous	Senonian	Hard thin limestone, light brown and green; lenses of blue and red shale in upper part
Rudistes			Turonian Cenomanian	Thick limestone, compact, cavernous, hard, fine-grained, shelly, gray-brown, few shale breaks

TABLE I—*Continued*

Paleontology	*Origin of Sedimentation*	*Thickness of Beds; Maximum or Range (in Feet)*	*Tectonics*	*Indications of Oil*
Foraminifers, corals, echinoids, brachiopods, gastropods, *Rotalidae*, *Pecten*, *Chlamys*, *Ostrea*, *Miliolidae*	Coastal and continental	5	Intermittent transgression and sedimentation, of type now in progress	
No fossils	River	2,000	Post-Pliocene movements followed less active post-Miocene, with quiet period between; followed by retreat of sea, with important land masses appearing	
Generally no fossils; locally remnants of mammals (*Hipparion gracile*, *Rhinoceros Morgani*, *Aceratherium persiae*), birds, brachiopods	Lake, marine epicontinental	13,000	General transgression and continuous unconformity of Pliocene, on underlying beds. Post-Miocene movements, very important and abrupt, gave origin to Iran Mountains	Asphaltic inclusions
Imprints of plants, traces of *Annelidae; Miliola*, *Polystomella*, and gastropods	Marine epicontinental	100-3,000		Seepages at base
Imprints of plants and of *Annelidae*; *Miliolina*, *Spiroculina*, *Textularia*, *Globigerina;* hydrozoans; echinoids; brachiopods; *Chlamys multistriatus*, *Venus aglaurae*, *Ostrea virleti*, *Astarte hyderabadensis*	Laguno-marine	1,000-2,500	Continuous sedimentation, quiet period, uninterrupted to upper Miocene	Seepages
Globigerinidae (*G.* and *Sphaeroidina bulloides*); hydrozoans; echinoids; brachiopods; *Pecten substriatus*, *Ostrea* cf. *multicostata multicarinata*, *virleti*	Lagoon	4,900		Very petroliferous
Alveolina (*A.* cf. *Melo*), *Miliolina* (*M. Valvularis*), *Myogypsina burdigalensis*, *Cardium burdigalinum; Leipdocyclina dilatata* and *Mantelli*, *Pecten rotundatus; Nummulites* (*N. intermedius*), *Heterostegina*, *Agmaria*, *Cytherea incrasata*	Marine	4,600	Post-Oligocene movements, deposition in geosyncline, less and less deep, local land masses appear representing anticlinal features of to-day	Very petroliferous
Schizaster rimosus, *Ditremaster nux*, *Pericosmus*	Marine	250	Transgression of Lutetian, followed by continuous sedimentation to Upper Asmari	
Alveolina (*A. ovoidea*), *Miliola* (*M.* cf. *bloculina*), *Assilina* (*A. spira*), *Nummulites* (*N. laevigatus, perforatus*), *Orthophragmina* cf. *umbilicata*	Marine	600-1,600		Weak local seepages
Orthophragmina, *Globigerina*, *Sphaeroidina*, *Lithothamnium*	Laguno-marine	1,200	Pre-Lutetian movements, affecting the Cretaceous folding	
Omphalocyclus macropora; Hemiaster, *Iraniaster*, *Hemipneustes; Terebratula* (*T. Toucasi*, *Brossardi*); *Pycnodonta vesicularis*, *Exogyra Matheroniana*, *Lopha dichotoma*, *Plicatula hirsuta*, *Neithea striaticostata; Campanile*	Marine	620-1,200	Sedimentation discontinued, corresponding with Cretaceous movements to Danien	
Orbitolina cf. *concava; Sidaris* (*C. cenomaniensis*), *salenia* (*S. scutigera*), *Holectypus* (*R. cenomaniensis*); *Exogyra colomba*, *Biradiolites*, *Radiolites*, *Sauvagesia*, *Durania; Acanthoceras* (*A. rotomagense*)	Marine	1,500		

RECENT PUBLICATIONS

CANADA

"Oil and Gas in Western Canada," by G. S. Hume. *Canada Geol. Survey Econ. Geol. Series, No. 5* (Ottawa, 1928). 152 pp., 14 figs. Price, $0.25.

ILLINOIS

"The Dupo Oil Field in Southwestern Illinois," by A. H. Bell. *State Geol. Survey, Illinois Petroleum, No. 17* (Urbana, 1929). Price, $0.25.

PENNSYLVANIA

"Pittsburgh Quadrangle," by Meredith E. Johnson. *Pennsylvania Geol. Survey Topographic and Geologic Atlas, No. 27* (Harrisburg, 1929). 236 pp., 33 illus. Price, $1.00.

POLAND

Le Petrole en Pologne, by Michel Alberg. (A. Francke, S. A. Berne, 1929). Price, 7. 20 francs.

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The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of the applicant.)

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Memorial

JACK JOSEPH KING

Jack Joseph King died in Fort Worth, Texas, January 17, 1929, from injuries sustained in an automobile accident while en route from San Angelo to Fort Worth. Jack and Paul L. Keller, his companion on the trip, were struck by a car while changing a tire, 20 miles from Fort Worth. They were rushed to the All Saints Hospital at Fort Worth, and arrived there at 11:00 P. M. Medical aid proved futile to Jack and he passed on at 9:20 the following morning.

Jack Joseph King was born in Houston, Texas, September 21, 1902. He was the only child of Mr. and Mrs. Jack J. King. He graduated from Laredo High School in 1920 and attended Rice Institute in Houston for one year in 1920. He entered the University of Texas in 1923, graduating from this institution in 1927, with the degrees of B. A. and M. A. in geology. He also specialized in law and passed the Texas bar examination. During his stay in the University, he became a member of the *Chi Phi* and *Sigma Gamma Epsilon* fraternities, and after finishing college, he was elected to the American Association of Petroleum Geologists. He was also a member of the Masonic order.

After graduating from college, he became associated with the firm of Ricker and Dodson, San Angelo, Texas, in the capacity of geologist, and later he was connected with the Taylor-Link Company, also of San Angelo. On December 27, 1927, he entered the employ of the Peerless Oil and Gas Company, and was engaged in doing geological work for them in West Texas. He left this company January 1, 1929, to do independent consulting work, with headquarters in San Angelo.

Mr. King was united in marriage to Miss Velta Pardue, of Hamlin, Texas, on September 1, 1928.

Due to his training in both the geological and legal professions, and to his keen business mind, he had an exceptionally bright future in the oil business, and it is with deep regret that we, his friends and companions, must chronicle the untimely end which cut so short his promising career.

Those who knew Jack loved him, and his many friends and associates feel, more keenly than words can express, the tragedy which befell him. The memory of his genial disposition, his engaging personality, and his generous hospitality will remain with us during the years to come.

H. H. HENDERSON

SAN ANGELO, TEXAS
February, 1929

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

E. S. PRATT, geologist for the Shell Petroleum Corporation, has been transferred from Ponca City, Oklahoma, to take charge of the geological department at Wichita, Kansas. Other Shell geologists at Wichita are CLARK MILLISON, J. B. HOOVER, L. R. FORTIER, H. M. STANLEY, and J. D. MCCLURE.

The San Antonio Geological Society has been organized with the following officers: president, CHARLES H. ROW; vice-president, R. F. SCHOOLFIELD; and secretary-treasurer, KENNETH OWEN.

GEORGE H. NORTON, recently with the Gypsy Oil Company at Wichita, Kansas, has accepted a position with the Atlantic Oil Producing Company, Tulsa Trust Building, Tulsa, Oklahoma.

OLAF P. JENKINS is at present doing research work on a problem in California geology. His address is Stanford University, California.

D. F. HIGGINS, JR., of Loveland, Colorado, has been appointed lecturer in petroleum geology in Northwestern University, for the second semester of 1929. He is giving a course on the geology of petroleum.

LOUIS ROARK is on the geological staff of the Red Bank Oil Company, with headquarters at Tulsa, Oklahoma.

HANS E. THALMANN has been transferred from Tampico. His address is El Aguila, S. A., Apartado 86, Puerto Mexico (Vera Cruz), Mexico.

D. D. CHRISTNER is in charge of geological work for the Marland Production Company at Fort Worth, Texas.

J. B. TEMPLETON has returned from a stay of three months in Venezuela and is at 502 Mid-Continent Building, Tulsa, Oklahoma.

A. W. MCCOY is in charge of the land and geological departments of the Ponca City Oil Company at Ponca City, Oklahoma.

E. F. DAVIS, formerly chief geologist of the Shell Company of California, has been made vice-president.

CARL H. BEAL, A. H. HELLER, and GRANT CORBY have opened consulting offices in the Quinby Building, Los Angeles, California.

J. C. TEMPLETON has been engaged in a torsion-balance survey of the northern plains between El Mene field and the coast of Venezuela. His work includes a survey of the Orinoco delta.

ARTHUR WADE, consulting geologist, 19 Basinghall Street, London, is on a professional trip in the United States and South America.

M. E. WILSON resigned his position as superintendent of production for the Louisiana Oil Refining Corporation at Shreveport last March to become vice-president in charge of production, pipe line, and geological departments for the Lion Oil Refining Company at El Dorado, Arkansas.

W. L. WALKER, chief geologist for the Empire Companies for the past three years, is in California in charge of special work for the Cities Service.

J. M. NISBET has succeeded W. L. WALKER as chief geologist for the Empire Company at Bartlesville, Oklahoma.

E. GAIL CARPENTER is with the Independent Oil and Gas Company. His address is 1800 West Parker Avenue, Wichita, Kansas.

The first annual meeting of the ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS was held at Edmonton, March 1 and 2, 1929.

This society was organized January, 1928, with the object in view of bringing together all persons actively engaged in geological exploration for oil in Alberta. The society is limited to *bona fide* members of the geological profession only, and the requirements for members are the same as those for the American Association of Petroleum Geologists. The technical program is here given.

1. Salt and Gypsum in Alberta, John A. Allan.
2. Interpretation of Some Structural Features in the Central Alberta Foothills Area, T. A. Link.
3. The Geological History of Southern Alberta during Late Cretaceous and Tertiary Time, J. O. G. Sanderson.
4. The Foremost Pakowki and Milk River Formations in Southeastern Alberta, H. M. Hunter.
5. Geological Observations on the Western Portion of the Cypress Hills, D. L. Powers.
6. Some Features of the Mesozoic Sediments between the Athabasca and Peace Rivers, A. J. Childerhose.
7. Regional Geologic Structure of the Prairie Provinces, B. F. Hake.
8. The Stratigraphic Position of the Kootenay, P. S. Warren.
9. Subsurface Stratigraphy of the Turner Valley Structure, P. D. Moore.
10. Post-Pleistocene Uplift in Alberta, Ralph R. Rutherford.
11. Salient Characteristics of Pre-Montana Cretaceous Sediments between the Bow and Berland Rivers, J. B. Webb.
12. Presentation of Sections Showing Dakota Correlations at Various Points in Montana and Wyoming, E. H. Hunt.
13. Comparison of Stratigraphic Sections in Montana and Alberta, R. V. Johnson.

At the annual banquet the following new officers were announced for this year: president, Theo. A. Link; vice-president, P. S. Warren; secretary-treasurer, H. M. Hunter; business representative, B. F. Hake.

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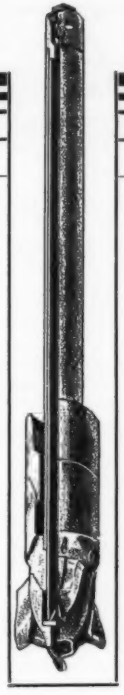

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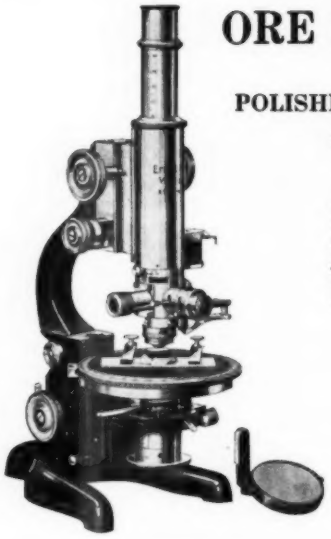

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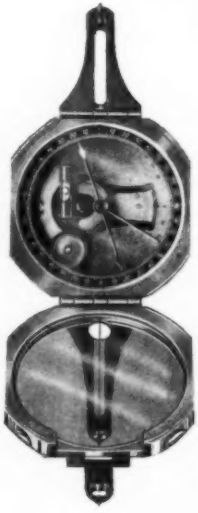

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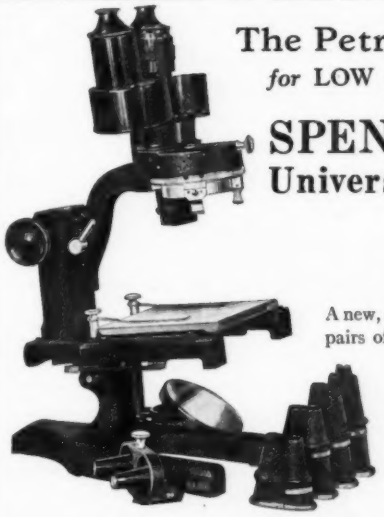

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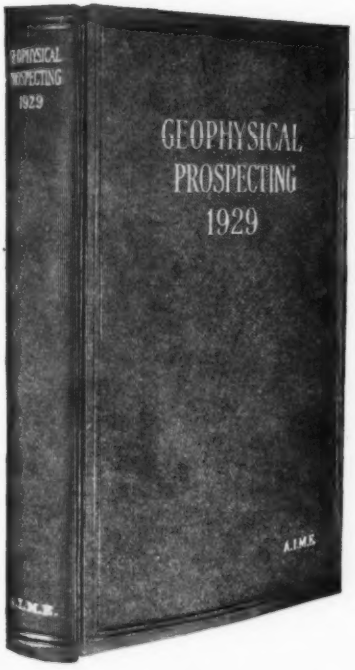

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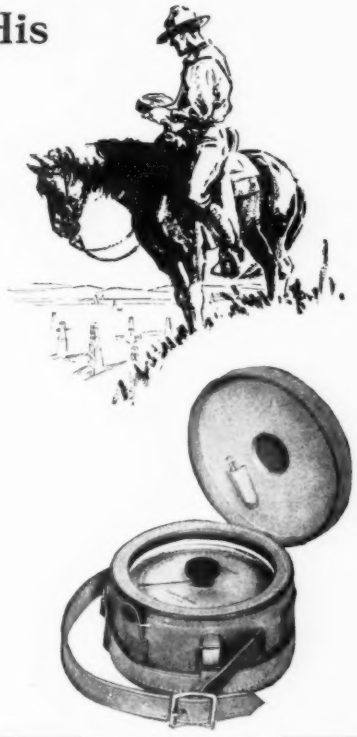

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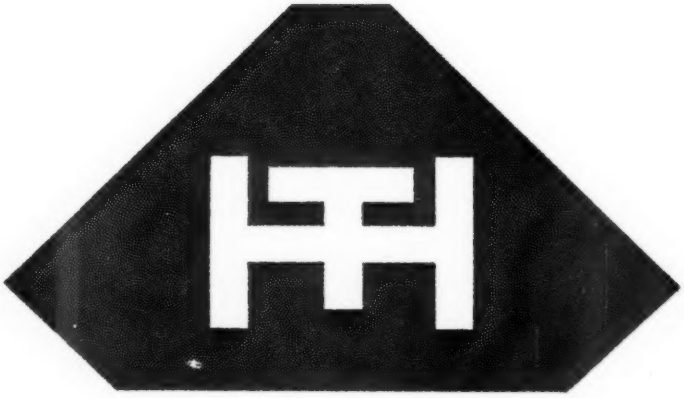

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